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PROCEEDINGS

SECOND MEETING, SECOND HALF, 65TH SESSION

The Second Meeting of the second half of the 65th Session of the Royal Aeronautical Society was held in the Lecture Theatre of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C.2, on Thursday, January 23rd, 1930. The President (Colonel the Master of Sempill) was in the chair.

The PRESIDENT: The paper was one which was bound to raise considerable discussion. If we believed that, to be effective and permanent, air power, like sea power, must be based on a sound economic foundation in peace time, then it was the duty of the Society to do everything possible to make that economic foundation as solid and broad as it could be made. Therefore, the Society had looked forward to hearing the paper by Mr. Howard, who was responsible for the technical work connected with the issue of certificates of airworthiness, under the Air Ministry, and to whom, on behalf of the Society, the President extended a hearty welcome.

CERTIFICATES OF AIRWORTHINESS

BY

H. B. HOWARD, B.A., B.Sc., A.F.R.Ae.S.

The object of the present paper is to place before the Society certain general considerations regarding the effect of airworthiness regulations on the design of civil aircraft.

I should like first to thank the Air Ministry Authorities for permitting me to read this paper, and to explain that any opinions expressed are entirely my own.

The Air Navigation Regulations, which set up organised Government control of civil aviation in this country, came into effect on the 1st May, 1919, so that the influence of Government supervision has been present during the whole period of post-war development of civil aviation.

The law protects those members of the public who wish to fly, and more particularly those who pay to do so, in numerous ways.

Before a passenger-carrying aircraft can fly, the pilot, the navigator, the ground engineer and the aerodrome must all be licensed. The instruments and equipment must be of approved types, and lastly the aircraft itself must possess a certificate of airworthiness. Moreover, this certificate must be renewed yearly after a thorough inspection.

The granting of the certificate is conditional upon compliance with a host of regulations, covering the design, materials of construction, and workmanship in the aircraft. So wide a field is covered that only a few points can be touched on here, and I am accordingly only considering the certificate of airworthiness as it affects the design of the aircraft itself, apart from the engine.

Safety in any form of transport is a relative term, and this seems especially true of aviation.

With increasing knowledge, our view of what constitutes a safe aeroplane automatically changes.

Aircraft which a few years ago were regarded as thoroughly satisfactory would now be considered relatively dangerous. In fact, many of the types which have made aeronautical history could certainly not have been granted a certificate of airworthiness. But this is not a criticism of the system. The general public cannot be expected to take the same risks as the pioneer.

All that regulations should do is to crystallise informed opinion as to the minimum desirable standards; but these standards are in many particulars still a matter of opinion and therefore of controversy.

We have in consequence to give a legal meaning to the term "airworthiness," by means of specific rules which must, in very large measure, be entirely empirical.

Now it might be supposed that these safety precautions would not exercise any great influence over the design, and that they merely stop the designer from doing something he would not want to do in any case; that they were, in fact, on a par with the law which prohibits you from marrying your grandmother. But this is not the fact. Some of the most vital safety conditions are fundamental in the lay-out of the design.

I do not for one moment suggest that with no legal restrictions no safe aircraft would be produced. If the law did not lay down minimum airworthiness conditions for him, the designer would lay them down for himself. The two sets might quite reasonably differ in details, but in either case they would be of fundamental importance.

Compared with other forms of transport, safety considerations play an immeasurably greater part in the design of aircraft, and incidentally in the commercial value of the resulting vehicle.

From this point of view the design features of an aircraft can broadly be divided into two groups: first, those attributes which can be corrected by a "trial and error" process, such as stability and controllability, which even if found unsatisfactory on a first trial can usually be corrected by changes in the size or disposition of control surfaces; second, those qualities which are fundamental in the design and which cannot be subsequently modified to any great extent. The principal example in this class is structural strength. Other cases are horse-power and surface loading to achieve a safe take-off, and a system of load distribution to give a satisfactory position for the centre of gravity.

It is of paramount importance, therefore, that the legal provisions shall be so drafted that they represent the best current practice in airworthiness. Only by this means can the designer be given the maximum legitimate measure of freedom. Briefly, the law should only impose those restrictions which the experienced designer would impose upon himself.

I propose to discuss briefly certain aspects of this problem which seem to me of basic importance.

Take-off Requirements

It is required that every new type of civil aircraft submitted for a certificate of airworthiness shall clear a barrier 20 metres high in a certain stated distance, starting from rest, against a wind of not more than 2.5 metres per sec., and in addition climb to a stated height in three minutes. These times and distances vary with the class of aircraft, and the figures are as follows:—

Type.	Distance to climb 20 metres.	Height to be climbed in 3 minutes.
Public transport for passengers	500 metres	420 metres
Special category aircraft ...	750 ,,	360 ,,
Other aircraft	600 ,,	360 ,,

The intention of these regulations is obvious. The barrier test is to ensure that on taking off the aircraft will clear houses, trees, etc., on the edge of the aerodrome. The climb to height is to ensure that a safe flying height can be reached sufficiently rapidly to minimise the risk of engine failure near the ground.

These standards are identical with those agreed internationally as minima, except for the passenger carrying class. Here we have nationally reduced the distance in the barrier test from 600 to 500, and increased the height in three minutes from 360 to 420 metres.

It might be noted that these two conditions are not, nor are they intended to be, consistent. An aircraft may satisfy one without satisfying the other. Broadly, the climb to height usually limits the weight of the lightly loaded, lower speed aircraft, and the barrier test that of the higher speed, more heavily loaded, types. It is, I think, open to argument whether this secures the same measure of safety on all types. In three minutes from rest a high speed passenger carrier will, even at its climbing speed, have travelled a considerable distance. In a country of so uneven a contour as our own it might be preferable to satisfy that a safe height had been reached in a certain distance, rather than in a certain time from rest.

The necessary standard of take-off performance is largely determined by the available aerodromes and the nature of the country over which flight is intended. The choice of a suitable aircraft for particular operational conditions is left almost entirely to the judgment of the operator. No special reference is made on the certificate to these conditions. The take-off requirements have accordingly to be adjusted to what may be broadly termed normal conditions in this country. There seems the possibility that this may handicap the development of specialised aircraft. Under existing procedure, for example, the same take-off requirements apply to a small light plane two-seater for training purposes or taxi work as to the large passenger carrying type. The latter, perhaps, would always operate on large aerodromes of good surface, and under closely watched conditions. Provided a good angle of climb is achieved on leaving the ground a long run to unstick would appear less detrimental than in an aircraft required for general use on any aerodrome.

Structural Strength

In our present state of knowledge, the answer to the question, " Exactly what strength should this aircraft have?" is, to be perfectly candid, " Nobody knows." But this confession of agnosticism need cause no alarm. We know enough to make aircraft safe, but we do not know how safe we have made them.

The first obvious and broad dividing line lies between the " acrobatic " aircraft, which are allowed to stunt, and the " normal " aircraft, which are not.

For the " acrobatic " class there is a fair body of evidence as to the loads encountered. Accelerometer measurements have been made in this and many other countries during " acrobatics."

Our system of load factors is built up very largely on this kind of evidence. In this branch structural safety is in the hands of the pilot. The designer can only provide the strength which past experience indicates that the pilot ought to require. The responsibility for not over-stressing the aircraft is then on him. The human element is the obstacle to an exact solution. The factor of safety may be the factor of ignorance, but the ignorance is not what the pilot can do with the aircraft, but what he will do with it.

New developments in control and new manœuvres to which aircraft are put need to be constantly watched from the structural point of view to ensure that reasonable margins of strength are provided.

In the " normal " category the position is different. No acrobatics are in question, and under similar conditions different pilots ought not to produce greatly differing loads on the structure.

It seems reasonable to expect that the importance of the human element will be relatively less. But we are faced with an almost complete absence of satisfactory data of the loads encountered. It was from the outset obvious that lower load factors would be allowed in this class, and accordingly these were reduced to about two-thirds of their value for acrobatic aircraft. The result, as shown by the published reports of accidents, has been that British air transport services have covered some 8,000,000 machine miles without a single accident attributed to structural failure. The chance of such failure may, therefore, be regarded as, for practical purposes, zero. The inference is either that we have got our aircraft just right, or that we have got them too strong. Remembering the arbitrary nature of our methods for determining strength, the suggestion that we have got our aircraft just right is wildly improbable. There seems therefore some reason to hope that strength factors might be reduced in the air liner class without any practical reduction on their safety.

But it is very unwise to leap before you look. Few people keep this more constantly before them than Government Departments, and clearly something more than negative evidence is necessary before any substantial reduction can be made. Unfortunately such evidence is practically non-existent.

The kind of information needed relates to air speed and accelerations. If, for example, records were available showing that a certain type, over a number of flying hours, large enough to be of statistical value, never exceeded its top speed by more than 10 per cent., never encountered an upward acceleration of more than 2 g. nor a downward acceleration of more than $-\frac{1}{2}$ g., such information would form an invaluable basis for fixing its load factors.

I have only quoted figures to illustrate my meaning, but am of opinion that they would be found substantially correct for the large multi-engined passenger carriers.

If these kind of limits could be definitely established, maxima could be fixed for wing loads, tail loads, etc., and a scheme of strength specification built up on a far sounder evidential basis than we at present possess. Such evidence would further enable us to distribute the strength of our aircraft structures in the most efficient manner, and thus aid us in the reduction of structural weight.

Much remains to be done to make our knowledge of the structural problem more precise. Almost every new development in aeronautics has its reaction on the structural side, and only by close and continuous study and a steady accumulation of data will the most economic use of material be achieved.

Accidents

The acid test for any system of airworthiness is the occurrence of accidents. Many safety provisions in aviation, as in other fields, owe their origin to this cause. The importance of their study needs no emphasis.

From this point of view the last ten years of civil aviation in this country show a very creditable record. Interesting details and statistics will be found in the Annual Report on the Progress of Civil Aviation, published by the Directorate of Civil Aviation. These include all the civil accidents investigated by the Inspector of Accidents under the Air Navigation Acts. All the following information is extracted from this source.

The last report, for the year 1928, indicates a progressive increase in safety on a statistical basis.

For the four years 1925-1928 there were no accidents in British air transport services resulting in death or injury to passengers. For other aircraft plying for hire over the same period there was only one person killed and one injured; for this latter class the machine miles per accident were 210,000.

But few as these accidents have been, their examination is none the less important. Since April, 1923, the above reports have included a very brief account of each accident, with an indication of the primary cause, and the following figures relate to the period 1st April, 1923—31st December, 1928.

The causes of the accidents may be classified in any number of ways, according to the particular purposes in mind.

The first broad sub-division lies between those caused by an error of judgment on the part of the pilot and others.

The Inspector of Accidents, in the above reports, indicates how many were, in his opinion, due to errors of judgment. I have prepared Table I from these figures:—

TABLE I.

Period.	No. of Accidents. Due to pilot's error of judgment.	Other causes.	Total.
1928	17	11	28
1927	13	11	24
1st April, 1926—31st Dec., 1926 (9 months)	11	1	12
1st April, 1925—31st March, 1926	5	0	5
1st April, 1924—31st March, 1925	4	8	12
1st April, 1923—31st March, 1924	13	13	26
Totals	63	44	107

Roughly, 60 per cent. of the accidents, according to these figures, are due to the pilot.

But the verdict " Error of Judgment " should, in many cases, be regarded as a criticism of aircraft in general rather than of an individual, and from our present point of view we need a closer examination.

I have accordingly prepared Table II.

TABLE II.

ACCIDENTS TO BRITISH CIVIL AIRCRAFT FROM 1st APRIL, 1923—31st DECEMBER, 1928.

Extracted from Annual Reports of Directorate of Civil Aviation.

Period.	Stalling near ground. 1.	Collision. 2.	Engine failure. 3.	Miscellaneous. 4.	Failure to recover from acrobatics. 5.	Structural failure. 6.	Total.
1st April, 1923, to 31st March, 1924	4	6	7	6	2	1	26
1st April, 1924, to 31st March, 1925	2	3	2	3	0	2	12
1st April, 1925, to 31st March, 1926	2	1	0	0	2	0	5
1st April, 1926, to 31st Dec., 1926 (9 months) ..	5	3	1	2	1	0	12
1927	5	7	6	4	2	0	24
1928	13	5	3	2	2	3	28
Totals ...	31	25	19	17	9	6	107

Here the accidents are divided into the following classes, according to their frequency over the whole period:—

(1) Stalling near the ground.

(2) Collision, either with other aircraft or objects on the ground.

(3) Engine failure.
(4) Miscellaneous causes (including weather) not affected by the airworthiness of the aircraft.
(5) Failure to recover from acrobatics.
(6) Structural failure.

In many accidents more than one cause is operative. The accidents have been classified according to the primary cause, so far as this can be ascertained. Some remarks on these causes are given below:—

(1) *Stalling near the Ground.*—Researches into low speed control are probably too recent to have affected the present figures, but there is no reasonable doubt that accidents under this head will be greatly reduced both in numbers and in consequential damage in future. Control at low speeds and beyond the stall is being continuously studied and our standards of safety in this respect, from the design point of view, are rapidly changing.

(2) *Collision.*—These accidents, though numerically a very large proportion, are often not seriously injurious to personnel. They are usually blamed on the pilot, and emphasise the need for a good field of view as a safety measure.

The next two classes (3) and (4) do not concern us.

(5) *Failure to Recover from Acrobatics.*—This class includes those cases of spins continued into the ground and loops carried out at too low a height. The spinning question, like low speed control, is also being studied continuously, and a better understanding is being achieved of the design requirements to render this manœuvre safe.

(6) *Structural Failure.*—This last, and smallest, class is of special interest in the present connection. Any serious structural defect in design results in a crop of accidents of the same type. No such tendency is observable here. The causes of the six accidents under this head vary greatly in nature. Such detail amendments in our regulations as they indicated have long since been made. Two of them were fatigue failures of fittings, to which a number of causes, other than the original design, may have contributed. One was the failure of the float chassis of a Schneider Cup racer which, in view of the specially severe conditions, is hardly relevant for civil aircraft in general. Another was due to the fraying of an aileron cable and was therefore partly a maintenance question. The fifth was due to the breaking of a safety bolt, a portion of the aircraft which has subsequently been brought under Air Ministry control, and the last was a failure of a wing structure during acrobatics, being the only one on a type of aircraft which has been flown very widely in this country.

It will probably never be possible entirely to eliminate structural failure, so varied are the causes to produce it, but from the design aspect there is no evidence to suggest that our standards are insufficient.

Certificates of Airworthiness from the International Aspect

The International Commission for Aerial Navigation is now engaged in unifying the minimum technical requirements in all countries signatory to the Air Convention. While the idea of international minimum standards is attractive, their establishment is a Sisyphean task. The process of adjustment of our ideas of safety to our state of knowledge renders it never ending. Moreover, there are racial differences which remain ineradicable.

An interesting example occurs in the question of structural strength. One group of nations prefers to test its type of aircraft to destruction; another to which we belong is prepared to rely on calculations. Now with aircraft structures, to bring two such systems into line so that they will have the same result in operation, is a practical impossibility. There will always remain considerable likelihood that an aircraft which passes by one system will fail by the other.

This type of difficulty is enhanced by the rapid and independent development of aircraft design in the different countries during the war. We then had no time to exchange ideas as to how aircraft should be built—we were too busy building them. Each nation, therefore, developed its own design technique and tradition which, when the time came for unification, had become partially stereotyped. Had civil aviation evolved naturally with a free exchange of ideas, the problem of internationalisation might have been simpler. This war inheritance is very evident both in our aircraft and our regulations.

But there are deeper differences needing to be reconciled. There is, for example, difference in the methods of use and maintenance. As an instance, from published records of accelerations obtained in America, it appears that American pilots habitually throw greater loads on their aircraft than is the practice here. If this is a fact, higher load factors on American aircraft would be essential to secure the same margin of safety.

Again, behind the actual design there lie the materials and method of manufacture, inspection and maintenance. Agreement on these is necessary, in addition to agreement on design rules, to achieve an equal standard of airworthiness.

Similar differences arise in the matter of take-off performance, though here they are topographical rather than racial. Variations in size, surface and altitude of aerodromes and in the contour of the country in general may reasonably find their reflection in the take-off performances demanded.

It can be argued that all that is required internationally is an agreement of *minimum* requirements, and that each nation is still free to stiffen up its own regulations. But such a proceeding might tend to create a feeling that the national laws are too severe and in addition tends to hamper a country in its foreign trade.

My own feeling is that internationalisation, though indispensable for some purposes can easily be pushed too far in others, and that experience alone will have to settle how far it is feasible and useful in aircraft design.

Conclusion

I have only attempted to indicate in outline a few aspects of a very broad question. It is one in which the free discussion afforded by this Society is especially valuable and I desire in conclusion to record my thanks for this opportunity of bringing it before you.

Discussion

The President: Whatever one's views might be as to whether or not the existing system was the best for the development of civil aviation, there could be no doubt that Mr. Howard was working that system in a very efficient and intelligent manner. Discussing the history of the development of regulations, the President recalled that in the Air Navigation Acts of 1911 and 1913 there were no regulations similar to these that had crept in since 1918, and, in view of the state of the art at that time, it would be admitted that the safety of civil aviation in those days was really quite remarkable in spite of the absence of those regulations. The first mention of regulations had been made by the Civil Aerial Transport Commission of 1918, of which the late Lord Northcliffe was chairman. In the Report of that Commission (Appendix A of the draft International Convention) it was stated that " The aircraft must be provided with a certificate of navigability issued by the authority of the State or Nation that possesses it." Certificates of airworthiness were mentioned in the International Air Convention signed on October 13th, 1919, and at the meeting of the International Commission for Air Navigation (which is the executive body under the Convention) held on 30th July, 1922. The United States had signed the Convention, but had never ratified it, because it had been placed under the direction

of the League of Nations. At the second meeting of the Executive, held in London in October, 1922, the Japanese delegate had raised the question of an international form of certificate of airworthiness, but it was not until several years later that airworthiness certificates of the same form for each of the contracting States were issued. The two most important non-contracting States were Germany and the United States of America. Until 1928 there was no regulation at all in America with regard to certificates of airworthiness, but in that year the Federal Act had come into force; prior to that each State had issued a separate certificate of airworthiness in accordance with its own standards. The President then said he would be glad if the Director of Civil Aviation could describe to the meeting the exact form of the present American certificate.

The whole subject was of the greatest possible importance, and there was no need to emphasise, to an audience such as was present that evening, the high standard of design and construction set by British aircraft. The question was, however, whether, in the light of commercial competition, that standard was or was not too high if, in fact, that were possible. It should be the aim of the Society to focus attention on the technical aspects of this matter, and by so doing, assist those other bodies which were giving it the very closest possible consideration.

Air Vice-Marshal Sir SEFTON BRANCKER (Director of Civil Aviation): Commenting upon a statement made by Mr. Howard as to the inadvisability of looking before leaping, he said that probably Mr. Howard did not really mean that! He, however, agreed to this statement to some extent; there was a tendency to play too much for safety and to continue " looking " while other people were getting ahead. Referring to the somewhat gruesome list of accidents given in the paper, he pointed out that those were the accidents investigated, and not necessarily accidents resulting in injury to personnel. He regarded collision as being one of the few real dangers which air transport had to face, and unfortunately collision usually did result in serious injury to personnel. Discussing the problem of Government responsibility, he pointed out that from the end of the war until 1927 there were no regulations at all concerning civil aircraft in the United States, and an enormous number of people had been killed and injured as the result of accidents to aircraft. During 1928, *i.e.*, just after the regulations had come into force regular air transport had very few accidents, but outside the regular air transport services something like 150 pilots and 210 passengers were killed; that was the direct result of the absence of regulations. In 1919, when the International Convention was drawn up and the International Commission appointed, the Government of Great Britain, together with most of the other Governments concerned with the Peace Treaty, had agreed that there were certain Government responsibilities which must be accepted; in order to carry those responsibilities properly it was necessary to make regulations, which were to represent the minimum standard for ensuring the safety of the public, not only in the air, but also on the ground. Since then the various technical experts on the International Commission had been striving to come to some agreement as to a minimum standard, but had failed; he did not think they would ever succeed. He believed the best solution was to adopt the practice we were already adopting, *i.e.*, to arrive at reciprocal agreements, by which the various countries agreed to accept each other's airworthiness certificates, although they might not all be based on the same minimum standard. This country had already agreed with the Americans, the Dutch, and, he believed, the Germans. Visits were first made to each other's inspection organisation and technical headquarters, and it was usually agreed that although the arrangements in one country might not be quite the same as in another, they were probably equally good. Two representatives of this country had visited the United States to study the methods adopted there, and we had come to the conclusion that an aircraft which secured

an export licence in the United States—which licence was issued in addition to the certificate of airworthiness—was up to our minimum standard required for safety. As to the adoption of a minimum standard, someone must decide what were the minimum requirements for safety. The International Commission had laid down certain requirements, to which we had agreed, and there were some to which no one had yet agreed. He pleaded that the requirements must represent the *real* minimum, but pointed out at the same time that the insurance companies must not lean on the certificates of airworthiness as proving that the aircraft to which they related were fit to do anything in the world. It was no use saying that a machine which was operating from a very large aerodrome at sea level was necessarily fit to operate from an aerodrome 300 yards long on the heights of Tanganyika. At the same time, Government did not want to specify different requirements for a machine to operate from an aerodrome at 1,000 ft. and for a machine to operate at another aerodrome at a different height; Government wanted to lay down a general minimum standard in order to ensure the safety of the public under average conditions. It was up to the operators and the insurance people to see that they employed aircraft which were suitable for the particular local conditions encountered.

Finally, he commented on the very fine reputation which the British airworthiness certificate had established throughout the world, a reputation so fine that the certificate was being used for a purpose for which it was never intended. It was intended purely to certify that a machine had met the minimum requirements laid down in this country to ensure the safety of the public, but it was being used, he believed, as a selling guarantee, because a machine with a British certificate was more easily sold than a machine without that certificate. At the same time, it was a great compliment to this country and to the supervision effected by the Air Ministry.

Mr. F. HANDLEY PAGE: He sometimes wondered whether a certificate of airworthiness was really needed for civil aircraft. The whole of our methods of dealing with aircraft had grown up out of wartime conditions, and under those conditions the principal purchasers of aircraft were those who made the regulations. The Government were using the aircraft and therefore had considered the whole situation from the point of view of standardisation and use in the field. So there had grown up a system which had started with the approval of, say, a nut and a bolt, and had gradually widened until it had embraced the complete aeroplane. He was not sure that that would have happened if we had started to build aircraft in the way that motor cars were built. There was really very little difference between the building of a motor car and the building of an aeroplane. There was one essential difference in the mode of operation of the two, however, in that the motor car travelled along the public highway, which was provided at the public expense, whereas the aeroplane flew over a man's property and, to the extent that the air above his property was his, it travelled through his property. For the reason that the individual had given up the property and had allowed the aeroplane to fly through it, the individual had to be protected, as had also the man flying in the aeroplane, and in consequence there was an elaborate system of regulations, national in the first instance, and ultimately becoming international, to cover the whole subject. He believed that the Government had only a very grandmotherly sort of interest in civil aviation, and were concerned to see that everybody was more or less safeguarded. The real interest was the interest of the man who made aeroplanes, to ensure that he would make them sufficiently safe to avoid accidents, and to continue to sell them. His interest was a very vital one. The interest of the man who bought an aeroplane, if he were going to fly it himself, was also a vital one, for he did not wish to get killed. Again, if he were going to operate it as a passenger-carrying machine, his interest was vital, because he would not secure passengers

unless he carried them in safety. Therefore, the men who made aeroplanes and the men who operated them were the people most competent to judge as to the qualities an aeroplane should have if it were to be safe. He made these remarks particularly in regard to civil aircraft because, with the extension of private ownership of aeroplanes, a very wide experience was being obtained, quite apart from experience in military use; the experience which was being obtained by manufacturers and users with regard to commercial conditions enabled them to know exactly was was required in an aeroplane, and in his view it was to some extent better than the experience inside a Government Department.

Mr. Handley Page went on to mention one or two particular instances in which certificates of airworthiness requirements are wrong at the present time—at the same time making it clear that the opinions he would express were purely personal and were not the considered opinions of any trade body. First, with regard to large machines, he said the strength of the fuselage was very largely determined by the nose-dive condition and, with machines built as they are to-day, the pilot could not exert the necessary force on his controls to bring the aeroplane into the nose-dive condition and so produce the conditions calling for the factor of safety which had to be provided in accordance with the regulations. The consequence was that machines were being built too heavy, whereas otherwise considerable savings in weight might be effected. Again, in view of the improvements effected in control at the stall there was not the same need as hitherto for rudder power or rudder volume. The size of the rudder was determined very largely by the condition at the stall, and if that size could be reduced, again the forces on the fuselage would be reduced, and further savings of weight could be effected. Mr. Howard had stated in the paper that in regard to the normal categories of aircraft we were faced with an almost complete absence of satisfactory data of the loads encountered. It would be advisable, said Mr. Handley Page, that experimental evidence should be obtained, so that we might be better able to assess the loads imposed on aircraft of the normal categories, and so that we might be able, perhaps, to revise the factors of safety. Throughout the paper Mr. Howard had referred continually to the empirical nature of the calculations and the data on which the factors of safety had been based, and there was no better illustration than his remarks concerning the difference between acrobatic and normal categories of aircraft, to the effect that the load factors in respect of the normal aircraft were taken as being about two-thirds of their value for acrobatic aircraft. That indicated that a good deal more data were needed than at present existed of the actual loads encountered in normal flight.

From the national survey, he continued, one came last of all to the certificate of airworthiness of the I.C.A.N. Here one was up against a great many difficulties. To obtain a British certificate of airworthiness a machine must meet certain minimum requirements, but in order to ensure that his machine would meet all the requirements a constructor used materials which would withstand loads perhaps 10 or 15 per cent. greater than the minimum loads specified. For example, the flying wires might be 15 per cent. stronger than they need be to withstand the minimum loads specified. On the other hand, one was quite convinced, from examinations of foreign designs, that in many cases the machines produced abroad were made sufficiently strong to be able to meet the minimum requirements and no more. Here one was concerned with the psychological interpretation of the minimum requirements. In one country it was thought that a margin was necessary over the minimum requirements, whilst in another it was considered that if the results of the tests were within 1 or 2 per cent. of the minimum requirements that was good enough. On top of that there was the difference between a sand load test, in which the load was put on in some empirically determined manner, and a calculated failing test, determined in the most accurate manner possible according to the loads as one saw them coming

on to the machine. The factor of safety of a particular type of machine abroad might be stated as 10 or 12, whereas in this country it was only 7 or 8; when the two machines came to be tested in the same way it was found that there was no difference between them, or it might be found that the machine having a factor of safety of 10 or 12 would break down before the machine with the calculated factor. It seemed to him that eventually they would get back to the same kind of conditions that prevailed in regard to the building of ships. People liked to travel in British ships because they knew those ships were sturdily built, and he hoped they would prefer to fly in British aeroplanes because they felt confident that the wings or rudders would not come off, and that generally they would reach their destinations safely. The ultimate test would be whether the aeroplane was safe to fly and whether the operating company operated it under satisfactory conditions. He personally believed that the more flexible the requirements became for obtaining certificates of airworthiness, and the greater the reliance placed upon responsible people in manufacturing and operating, the greater would be the progress made; he would like to see a little less regulation and a little more flexibility. One was perhaps apt to overlook the far-reaching effects of regulations; they had a way of cropping up at most inconvenient times during production, and particularly in mass production, and indicating to a manufacturer that he must alter this, that and the other at a time when perhaps 100 or 150 parts were going through the shops, and they were responsible for very serious increases in costs of production. One of the greatest difficulties was to produce aeroplanes cheaply enough to enable people to buy them, and he believed that if some of the certificate of airworthiness requirements were less definite, and if more were left to the individual manufacturers and operators, more progress would be made than by trying to tie everyone down to particular requirements in a legal sort of way.

Major R. H. Mayo: Mr. Howard might justly be proud of his association with the British Airworthiness Department, because the work of that department had played an important part in the establishment of the high reputation of British aircraft and British aviation. He did not agree with the suggestion that airworthiness certificates should be abolished altogether. Mr. Handley Page had perhaps forgotten that there might be new aircraft constructors starting up who would lack the experience of the old established firms. He would have thought that the regular established aircraft constructors would have been glad to have a standard of airworthiness, and that a fairly severe standard, if only to protect their own interests. Commenting on Mr. Handley Page's remarks concerning the restrictive effect that regulations might have during the process of manufacture, he said that much depended upon the interpretation of the regulations. It seemed to him that in this country they had been fortunate by reason of the reasonable spirit in which the regulations had been interpreted, on the design side by the Airworthiness Department and on the constructional side by the A.I.D. The two shipping classification societies—Lloyds' Register of Shipping and the British Corporation Register of Shipping and Aircraft—had recently extended their activities to include the inspection and survey of aircraft, but he could say from personal knowledge that the British Corporation Register had no desire to encroach upon the work of the Airworthiness Department. It hoped, however, to carry out useful work in the inspection and survey of aircraft, with a view to ensuring maintenance of airworthiness in service.

Discussing the detailed airworthiness requirements, he said he was glad to note Mr. Howard's remarks as to the possible revision of structural strength requirements. As Mr. Howard had remarked, it would be foolish to embark on any relaxation of the regulations until they had definite information that such relaxation was justified. Experimentation on the lines suggested was in progress, and there was hope that within the next few months evidence would be available

which would be of assistance to the Airworthiness Department in considering revision of the requirements. The problem was not by any means an easy one. One might have an aircraft which it was perfectly safe to operate under the conditions prevailing in this country or anywhere in north-west Europe, but if that aircraft happened to fly out to tropical or mountainous regions it might be structurally unsafe under the much larger accelerations which might be met under those conditions. If aeroplanes had to be limited to operation within particular zones, commercial aviation might be hampered, and the problem would therefore have to be approached with very great care. If, however, the observations made did show that some reduction of structural strength could be allowed, then most certainly it ought to be allowed. God forbid that British factors of safety should be reduced one iota below the safe limit, but if one could effect only a small saving it would be of great advantage to do so. In this connection he pointed out that the Airworthiness Department could not exercise control over detailed design from the point of view of durability in service. In his experience the question of durability of detailed design had been at least as important as that of main structural strength, for the reason that the main structure did not fail, whereas detail fittings did sometimes fail, particularly after having been subjected for considerable periods to wear and vibration. Any saving that could be effected in the main structure—or at any rate some of it—might well be applied to increasing the robustness of detail design; if that were done he believed it would be a distinct gain from the point of view of the aircraft operator.

With regard to accidents, it seemed to him that the items which comprised the largest percentages in Mr. Howard's table should receive the most careful attention. With regard to accidents due to stalling near the ground, a very great improvement had been effected; Mr. Handley Page and his firm had made a most important contribution in this direction. The next most important item was that of collision, and Table II showed that no less than 25 out of 107 accidents were due to that cause. It was true that some of these accidents had not resulted in serious injury to personnel, but, nevertheless, they were accidents. Moreover, if there had been that number of accidents due to collision during these early years of civil aviation, he ventured to predict that there would be an enormous number of such accidents during the coming years unless proper precautions were taken to prevent them. In his view that was one of the most important factors in the airworthiness of civil aircraft. The fact was that they were only just at the beginning of general flying by the public, and as it increased so the risk of accidents due to collision would increase enormously. He ventured to say that the present standards of vision for the pilot were quite inadequate. In large commercial aircraft and in certain other types the pilot was placed in a position from which he could see, but in the majority of civil aircraft he was placed in such a position that he could not see properly. When the air became congested with aircraft, and when people were flying more in fog and cloud, the pilot would need an unobstructed view. A " blind " aircraft was a menace to all other aircraft and he thought that from now onwards no aircraft should be passed as airworthy unless an adequate field of view were provided for the pilot.

Finally, he agreed with Mr. Handley Page that the question of international agreement was really not one of very much importance. They had succeeded in putting their house in order, and if they kept it in order in the future they would not have much to worry about. They had set a standard of safety which was being appreciated gradually all over the world, and even if foreign designers were able to secure a certain improvement in some features of performance at the sacrifice of safety, Great Britain should be able to hold her own in the long run.

(*Communicated.*)—While believing that the maintenance of certain minimum standards for airworthiness is desirable, he certainly agreed with other speakers

that there is room for improvement in certain matters of procedure. In particular the present procedure for the testing of performance of new types imposes a serious restriction on the industry. Type trials at Martlesham Heath nearly always involve serious delay, not through any fault of the personnel there, but owing to congestion of military work. This is serious to both constructors and purchasers as time is nearly always of great importance in the early development of a new type. There is the further consideration that heavy cost for insurance, etc., is involved in sending the aircraft to an official station. Surely it would be better for such tests to be conducted at the manufacturer's own aerodrome, under official observation where necessary. The flying could be done by an approved pilot who could in general be the firm's own test pilot.

Captain DE HAVILLAND: The great difficulty for the manufacturer was not so much the regulations themselves as the manner of their application. He disagreed with almost all Major Mayo had said, especially the suggestion that the regulations were interpreted in a very generous spirit. He felt that most aircraft firms would prefer to be entirely free from Government regulations, because those firms must realise that in any case the responsibility for soundness of design and construction, and safety, rested with themselves ultimately. If they must have regulations, however, then they must be reduced to the very minimum and must be administered rather in the spirit of the law than the letter of the law. A very essential matter was that of standardising airworthiness certificate requirements internationally, because under present conditions it was almost impossible for British manufacturers to compete in foreign markets with Continental rivals, even though the British machines were actually superior to the foreign ones. The subject of the method of applying technical regulations was so vast that one could not go into it very deeply at a meeting, but the application of the regulations was adding very considerably to the cost of British machines. Mr. Walker had gone into this matter in some detail, and would be pleased to deal with some of the points. Finally, commenting on Sir Sefton Brancker's remark that the British certificate of airworthiness was considered a hall mark of quality, Captain de Havilland said that surely that was due to the excellence of the British machines in being able to comply with the C. of A. requirements.

Mr. C. C. WALKER: He would like to congratulate Mr. Howard on his treatment of a subject which could easily have been obscured by a mass of detail. There is, however, the drawback to this method that anyone unfamiliar with the subject would think the structural strength and " take off " were the only conditions to be met in obtaining a certificate of airworthiness, and would no doubt be surprised to learn that everything the constructor touches and every operation he performs, whether he is " approved " or not, is subject to regulation.

They in the industry had got so accustomed to regulation that they had to project their minds into some other industry to realise its extent. How would a motor car manufacturer fare if, besides satisfying himself and his customers, he had to convince a Government department about everything he did and every material he used—his speedometers, tyres, petrol cocks, gauges, nuts, bolts, how he locked his nuts, and how he tested his engines. If he made a modification, say, to the height of his dash or windscreen, or the weight or shape of his car, his steering gear, etc., he might have to send his car to a Government institution before being allowed to market it, where the amount of load it could carry, and the position of the load would be determined by experiments made without knowledge of its destination or use. There might be a long delay in which sufficiently neutral or adverse conditions could be encountered and when he obtains a certificate the document would inform the user that if he carries more than " X " passengers—" X " being calculated at 13 stone each—he must only go straight and not turn corners abruptly. The general tone would guard

against the user jumping to the conclusion that he had got hold of a good car. His 1930 model might with luck come out in 1931, but his troubles would not be over, for the Government department could circularise his customers without his foreknowledge, and always in the same warning strain. Some parts of his car might become non-approved for no reason that he or his customers could see. He would also be in a continual state of worry lest the trickle of new regulations might suddenly put him out of date and stop his production. If he goes out for an order from overseas with a small modification to type, he cannot give an acceptable delivery date because he does not know what procedure may be adopted by the department. He has to prove to the Government that each subsequent machine is identical with the type, and then pay a sum of money on each one he produces. On one type of aircraft alone this sum last year would have permitted the continual employment of about twenty-five additional skilled workmen.

This machinery of certification has grown up while the Government was practically the only customer, with the result that the new civil industry has to struggle into existence loaded with preconceived restrictions. Why should it not be recognised that an approved firm, the whole of whose design and construction is done under the eyes of Air Ministry representatives, is capable of making its own technical decisions. No regulations can alter the fact that the safety of aircraft depends upon the ability and experience of those who design and make them.

The present division of functions between constructor and Air Ministry, in which the Air Ministry has absolute control over both design and construction without being concerned about the efficiency of the product or even knowing what it is to compete against, is not rational and will be impossible under competitive conditions. It has only been possible to get along at all owing to the helpful goodwill shown by the Air Ministry in making this cumbrous machinery work. In particular the industry owes much to Sir Sefton Brancker and Air Commodore Holt.

He hoped and believed that under the present régime all these things are going to get better, but trade is a matter of seizing opportunities and time is important.

Mr. Howard has put the position as regards structural strength requirements so clearly and comprehensively that one can only express agreement with every word he has said. His analysis of accidents is also particularly interesting and informing.

So far as the " take off " and " climb " requirements are concerned, since the amount of load which can be safely taken off by an aeroplane varies in an extreme degree with the situation and circumstances, and a " safe " amount can never be specified except by someone on the spot within five minutes of the flight, it should not be made a condition of airworthiness. While it gives a very good description of the capabilities of the machine, and is quite suitable for regular air liners operating from Croydon, it becomes an absurdity when used to limit the paying load to the same extent in a small field in, say, Kenya as on a prairie in Brazil.

He must say that the idea of international minimum standards is quite appalling in its difficulty and, as Mr. Howard says, there will be no finality to it, and it all means very little for the reasons he has indicated, especially use, maintenance and varying levels of inspection. Why cannot the I.C.A.N. be left to settle the things that it is obviously useful to have settled internationally—such as rules of navigation, lighting, controls working the same way, etc. No one is going to build dangerous aircraft intentionally, and if unintentional the I.C.A.N. will not save them and the public will not use them.

In conclusion, he would suggest that the " get off " and " climb " requirement is eliminated as a condition of airworthiness and merely stated as part of

the performance, and that the machinery of the " approved firm " scheme be used to free the constructor from the present restrictions.

Air Commodore HOLT (Director of Technical Development, Air Ministry): There was likely to be some relaxation of regulations in the not far distant future. Owing to the extraordinary interest and hard work of the Airworthiness Department in the past, he said it was acknowledged that British aircraft had been free from structural failure to an extraordinary degree, whereas the aircraft of other countries, and particularly America, had suffered in marked degree. In view of this freedom of British aircraft from structural failures, Sir John Higgins had decided that the time had come when some relaxation might be made, but, as Sir Sefton Brancker had pointed out, the problem was a difficult one because the I.C.A.N. was also concerned, and it would take time to effect the desired modifications. It was intended that the resident technical officers at approved firms should take more responsibility.

Mr. W. D. DOUGLAS: Commenting on the fact that in some countries it was the practice to determine the strength of aircraft by testing a single aircraft of each type to destruction, whereas in this country they preferred to rely more upon calculations, said that occasionally it might be a good thing to test to destruction a single aircraft of a type, even though such tests were expensive, in order to give confidence to the people responsible for the calculations, and because all the parts of an aircraft are not equally amenable to calculation. If, however, it be decided to accept or condemn a complete design on the result of a single test, account must be taken of variation in the materials, which would affect the results obtained from the strength test. It has been said that this difficulty could be overcome by conducting a material test on the actual part that failed, but one cannot always rely on such a test for the correction of the failing load obtained in the test of the complete aircraft. At first sight it might appear that the failing load obtained on test could be increased in the same proportion as that by which the material of the part which had failed was below the required minimum strength. This problem has not, however, so simple a solution. Possibly, at the time when the part failed, there were other parts in the structure which were on the point of failure. The existence of such over-stressed parts cannot always be detected by subsequent examination. If it happened that these particular parts were made of material which was very much above the specified minimum strength, then if it was desired to obtain the true failing strength for that particular type of aircraft made of materials just up to the specification requirements, the value of failing load obtained on test, instead of having to be raised would actually have to be reduced. Thus variation due to material may appear in the result of a strength test even if check tests are made on the material of the part which fails.

Referring to the demand for definite information as to the accelerations to which civil aircraft are subjected during their normal life, he said that presumably such information could be obtained only by some form of indicating or recording apparatus which could be carried on the aircraft. Such apparatus must be very light, because it would constitute non-paying load. He believed that some small instrument could be devised for recording, at any rate, vertical acceleration. For example, it might consist of a small tube containing liquid, the tube being sealed at the bottom by a ground-in stopper held in place by an adjustable spring. If the vertical acceleration became great enough to overcome the strength of the spring (with the assistance of the weight of the liquid), a little liquid would escape from the tube and would be caught in a compartment below, which latter could be hermetically sealed. He imagined that small instruments of this type could be made and placed in different parts of the structure.

Major T. M. BARLOW: Discussing the international aspect, he deplored what he regarded as the loss of prestige in air matters internationally resulting from

the failure to insist upon the maintenance of the British standard of airworthiness and safety as a pattern for the whole world, and he urged that the Victorian policy which had operated towards the end of the last century in shipping matters, and which had established British commercial shipping as a pattern and standard for all countries, should be followed in respect of aircraft. It was not too late, and he did not see why, if we took strong and immediate action, we should have to commit ourselves to the signing of international agreements as the result of which the high standard for British aircraft may not be maintained. The adoption of the policy they had developed in regard to shipping had led to a great increase in our Empire and foreign trade, and he did not see why their aeronautical industry should not grow in prestige and size as the result of a similar policy in air matters. He agreed with Mr. Howard that internationalism could be pushed too far in certain respects, and this was so particularly when it led to interference in the standard of airworthiness. He could not see the need for international technical control by foreign bodies such as the I.C.A.N.

Then with regard to the " factor " question for airworthiness, as a matter of fact the numerical values were different. It was simply a question of what was defined by " safety factor." He believed that the I.C.A.N. used " collapse," which meant the complete breakdown of the whole aircraft for the ultimate factored load, whereas the general policy of British design factors was based on the yield or proof stress of the material of the aircraft. He complained that in this country the initiative of designers was hampered by too detailed regulations in connection with certificates of airworthiness, which went even so far as to direct how the leather safety belt should be made and worn. It seemed to him that that had not a very great bearing on the issue of such a certificate, and that an instruction of this nature was rather over-stepping the mark. Finally, he objected to the publication of certain of the British regulations in the metric system. The take-off requirements, and so on, were stated in metres, but he believed measurements were usually made with an ordinary tape measure in yards and feet and then converted to the metric measurements. Surely the British standard requirements should be stated in yards, feet and pounds instead of metres and kilos, and he saw no reason why they should change over to a system which foreign countries wanted to use for their own regulations.

Major J. S. Buchanan (replying to those who had asked why a certificate of airworthiness was needed at all): The psychology of the British nation at the moment was such as to demand it, seeing that at least 99 per cent. of the population really believed that flying was dangerous—and he was not sure that they were not right. After all, the British certificate of airworthiness represented only the minimum airworthiness requirements—or, at least, was intended to. It had been hoped that in time the insurance groups would have introduced a system of survey in regard to aircraft, similar to that of Lloyds in the shipping world. Then the Air Ministry could keep its regulations definitely to the minimum requirements for safety in flight, just as the Board of Trade issued regulations embodying the minimum requirements for the safety of ships at sea, leaving the insurance companies' surveyors to fix insurance premiums in accordance with the qualities of each aircraft, so that for increased airworthiness above the minimum requirement there would be a certain reduction in premium. It seemed to him that eventually they must have such a system. He was not quite sure whether or not the aircraft companies would find the insurance companies easier to deal with than the Air Ministry, but he should think not. After all, the Ministry did a very great deal of work for nothing, whereas one could be quite sure that the insurance companies would not. Commenting on Major Barlow's remarks concerning international load factors, he said he had the honour to be one of the British representatives on the I.C.A.N., and the difficulty was not that of getting the I.C.A.N. to accept a standard so high as the British stan-

dard, but rather that of convincing the I.C.A.N. that the British standard was satisfactory. Their factors of safety for the acrobatic class were of the order of $7\frac{1}{2}$, whereas the I.C.A.N. requirements were of the order of 9. Even on the basis suggested by Major Barlow, that they made their calculations and carried out their tests on the basis of the proof stress, as against the failing load, no system of calculation or the comparison of the calculations against a large number of recorded failures on sand loading tests would bring their requirements up to the nominal requirements agreed to by all other nations and the I.C.A.N. By any process of logical reasoning they could find they must come to the conclusion that they were still left with a nominally lower load factor for their aircraft than that supposedly enforced by other nations. That their load factors were adequate he was quite certain, but when dealing with certificates of airworthiness one should remember that the specification of load factors alone was a very small part of the problem. They did not experience structural failures in the air, and he attributed that result largely to the excellent materials they used and the excellent system of materials inspection. He believed they used the best materials in the world, and that the excellence of the materials more than made up for the so-called numerical deficiency of their load factors. Another important factor to be borne in mind was that whereas a machine might get a certificate of airworthiness one day, it might not be airworthy the next day; in other words, the problem of the maintenance of a machine while in use was at least as important as those of load factors and materials. It was safer to fly in an aeroplane with a low factor of safety, but which was well maintained, than in one with a high factor of safety but the maintenance of which was defective or inefficient. He believed their system of maintenance and inspection to be unequalled, and it had indeed produced the results expected from it.

Dealing further with international requirements as regards load factors, he said that in spite of their high standards, in respect of certificate of airworthiness requirements, every British aeroplane reproduced in America had to be stiffened up considerably in order to comply with the American regulations, so that on both sides of the Atlantic they were accused of having a low standard of airworthiness.

In a final reference to the doubts which had been expressed as to whether a certificate of airworthiness was needed at all, he pointed out that in this country every public vehicle which carried passengers for reward had to be licensed and certified by some public authority. The degree of examination varied from a complete and elaborate system, such as that which applied to shipping, to the lesser examination such as that applied by Scotland Yard in respect of taxi-cabs.

Mr. BRAMSON: It seemed to him, after listening to this amazingly provocative discussion, that the great trouble about certificates of airworthiness was that they could not really guarantee that the aircraft to which they applied were airworthy, so far as one could see. If they could he did not think there would be many objections; in fact, under those circumstances the failure to insist on certificates of airworthiness could not be defended. But, from the point of view of a pilot or a passenger in an aeroplane, one could not help coming to the conclusion that the regulations with regard to certificates of airworthiness were out of touch with actual flight conditions. What were the factors which worried a man when travelling in an aeroplane—the factors which might lead one to come to grief? First of all, in a typical single-engined machine a field of vision of approximately 15 degrees on either side of the centre line of the machine was totally obscured. One could not say seriously that an aeroplane to which that applied was really airworthy, any more than one could say that a motor car would be fit for driving on the road if its windscreen were non-transparent. Secondly, one might be flying in an aeroplane of, say, Continental type, which quite likely would obtain, and under present practice deserve, a British certificate

of airworthiness. Its gliding angle might be so small (owing to its high aerodynamic efficiency) and its gliding speed so great that one might feel that if the engine should fail one simply could not land in any reasonable size field. One could not say that that was really an airworthy machine if it had only one engine. Airworthiness had been considered in this discussion mainly on the basis of structural strength, but that was only a very small part of the complete requirements for airworthiness. A perfect engineering structure should be of uniform strength and durability. It was well known that it would be absolutely impossible to impose factors of safety on the individual parts of an aeroplane engine such as were imposed on the machine as a whole, and as a result most aeroplanes would outlast a large number of engines. The combination, therefore, did not really produce an airworthy aeroplane unless there were several engines. He submitted that to obtain a certificate of airworthiness a machine must be able to fly on after failure of one engine. One could continue indefinitely giving examples to show that the existing regulations did not actually ensure that the aircraft was airworthy, and it seemed that no matter what the regulations were, if they were kept within reasonable limits of interference with construction, they could not bring about that effect. Just as law was bad if it could not be enforced, certificates of airworthiness must be bad if they could not enforce airworthiness.

Mr. F. Radcliffe: Commenting on the point made by Major Buchanan with regard to load factors, he asked if it were not a fact that British load factors represented a factor of safety of one and a third on the probable load that would ever be imposed on a machine in normal use. If that were so, then they could not really regard those requirements as minimum requirements. As an example of the fact that other countries made their strength calculations in different ways from theirs, he mentioned that in America it was the usual practice to assume that when a machine was in high incidence flight only 80 per cent. of the load was carried by the wings; *i.e.*, the wings were loaded to approximately 80 per cent. of the loading they should adopt normally in this country, and, with a factor of 10, that became 8, whereas the British was $7\frac{1}{2}$. He believed a case could be made out very well for their own load factor, especially if regard were paid to the fact that their calculations were based on the yield or proof strength of the material.

It must be admitted that present types of aircraft were in no way permanent; they had by no means reached finality, and therefore there was need for more self-expression and development, which would be assisted if designers were left as unfettered as possible. Competition alone, and not legal restrictions, would lead to useful developments. A paper by the Hon. William MacCracken, of America (published in the December issue of the Journal), dealing with the regulations appertaining to civil aviation in America, was of great interest. It gave details of the requirements to be met before certificates of airworthiness were issued in America, and one important fact mentioned in that paper was that the Americans were not troubled with an A.I.D. to the same extent as they were in this country. More reliance was placed on the integrity of the designers, and the manufacturers' guarantee in respect of their products. The Hon. William MacCracken had stated that the underlying factors which controlled the development of any form of transportation were: (1) Safety; (2) reliability; (3) speed; (4) cost; (5) comfort. Mr. Radcliffe submitted that a Certificate of Airworthiness applied only to the first two items, and these in themselves were only paper statements in the Certificate of Airworthiness. In regard to safety, he said that a set of strength calculations had to be prepared which held up the progress of other design work to a considerable extent, and which, even when completed, covered only one section of design, viz., that of the primary structure. It was quite within the realms of possibility to produce a type with

a clean Type Record that would fall to pieces in the air shortly after getting through its acceptance tests, simply because its detail design was incorrect and inadequate. Some might reply to that: "What about the A.I.D. inspection?" The answer to that was that even the experienced eye could not replace calculations and a real appreciation of what the problem of detail design demanded, which must of necessity be left to the integrity and experience of the designer. This led him to put forward the following suggestions for consideration. It might be advisable, he said, to divide civil aircraft into two broad divisions—(1) the air liner, and (2) the privately-owned small type of machine which does not ply for hire. With regard to the air liner, carrying ten or more passengers, the traveller rightly demanded some guarantee that the aircraft in which he travelled was immune from the chances of accident which were within the control of man. The Certificate of Airworthiness, embracing *all* strength calculations, such as were produced by the design staff in the normal course of events, appeared to be a necessity, and those calculations should be submitted to the Air Ministry as a guarantee that all the necessary work has been carried out in the design of the structure. As to the small privately-owned type of aircraft, this was built with a view, it was hoped, to achieving something in the nature of continuous production, if it became a popular type supplying a real need. No Certificate of Airworthiness, or any other paper guarantee of strength, would really have much weight with the prospective buyer unless, from actual experience over a period of several years, immunity from avoidable accidents had been achieved. In other words, the true "Certificate of Airworthiness" was an invisible confidence on the part of the public in a type which was for sale, this confidence having been created by actual flying experience. This should be the aim of regulations relating to small aircraft—not to narrow down experiment, but to leave the designer sufficiently free to bring his inventive skill into play and so advance the technique and development of aircraft. Consider the young engineer with inventive genius and a desire to build his own type. The cost of a Certificate of Airworthiness alone would prevent many, other than the really wealthy, from getting beyond the dream stage. Aircraft must fly by themselves, and unless de-control could be achieved the aeroplane as a means of travel would not progress very quickly. Admittedly there were many obstacles in the way of the attainment of that state of affairs, but the young engineer was very insistent on this desirable objective being aimed at. The question of international Certificates of Airworthiness, of course, arose, and it would seem that a way out would be to limit these to air liners only.

Captain BALFOUR: One of the most vital phrases in the paper was to the effect that the law should impose only those restrictions which a designer would impose upon himself. Mr. Handley Page had referred to the Government's activities as being the outcome of grandmotherly interest, but in his (Captain Balfour's) view the Certificate of Airworthiness regulations were becoming positively like a mother-in-law to the aircraft designer. They were arbitrary and illogical. Sir Sefton Brancker had said that they could not have special regulations for a machine which was to fly from a high aerodrome in Tanganyika, and special regulations for an aeroplane which was to fly in England, so that they must strike an average. He (Captain Balfour) submitted, however, that to adopt an average such as that was to penalise the British aircraft manufacturer who wished to export his product, because it had no consideration for the use to which the aeroplane was eventually to be put. The man who wanted to use it might have an aerodrome as large as the Sahara, at sea level and in a pleasant climate, but because it could not get over the barrier it was limited in its range of use and probably would not satisfy the customer without a Certificate of Airworthiness. He mentioned that in order to show that the regulations were arbitrary. To substantiate his charge that they were illogical, he said that if the

Certificate of Airworthiness were to be a matter of regulation one might well say that the view to be provided should be taken into account—and one would like to know what was the official definition of a " satisfactory view." It would be very difficult to give it; people's vision varied. He presumed the medical department would specify angles of vision which would be permitted, and without which an aeroplane would not qualify. Equally, there might be a regulation with regard to durability, specifying that if the cost of repairs after a hundred hours flying were likely to exceed a certain figure the Certificate of Airworthiness should not be granted. These were regulations which logically could and should be introduced if the work were to be carried out. Mr. Howard had stated with some pride that the Certificate of Airworthiness system had resulted in British air transport services having covered some 8,000,000 machine miles without a single accident attributed to structural failure. He would suggest, however, that that result was not due entirely to the Certificate of Airworthiness system, but was possibly due to the British system of monopolistic subsidies. With regard to the procedure which had to be followed in order to obtain a Certificate of Airworthiness, he submitted that there was no other trade in the country which had to submit its products to a Government station. He sincerely hoped that in the not far distant future the Department of Civil Aviation would have its own establishment for licensing pilots, or, failing that, the regulations should be relaxed so as to enable pilots of civil aircraft to put their machines through the tests themselves—under Government supervision if desired.

With regard to international standards and Major Buchanan's statement that the I.C.A.N. was constantly telling them that their standard was very bad, he said he had noted that Major Buchanan had talked of the " supposed " regulations of the other countries. Possibly those regulations existed, but one wondered whether they were really adhered to or whether the I.C.A.N. was one of those splendid bodies at Geneva which legislated very carefully for strict regulations, knowing that the Britishers were about the only people who would adhere to them, and that the other countries concerned would set about building aircraft which would not meet the regulations which we had agreed to, and would capture our markets by selling those aeroplanes. The future would tell whether the system of bureaucracy creeping into a new industry would stifle it as only bureaucracy knew how. With Sir Sefton Brancker and Air Commodore Holt occupying their present positions things might be all right, but if in the future they handed over their duties to others, and if the regulations were carried out as they could be, most of those interested in the aircraft industry would close down forthwith.

Captain LYNAM: Speaking as one very directly concerned with the whole of the machinery in connection with airworthiness, he said that he felt, with Major Buchanan, that the requirements were very near the irreducible minimum—with one exception, namely, that the load factors might be reduced on commercial machines, and more particularly the large passenger-carrying machines. The load factors for that class of machine had been arrived at in a very arbitrary manner, and they did need evidence of the accelerations experienced in normal usage in different types in different parts of the world. Possibly also they needed some records of the maximum air speeds attained. With such information available, he believed that even the Airworthiness Department, and all those concerned with airworthiness, would feel justified ultimately in agreeing to some relaxation of the present requirements in regard to load factors in civil aircraft. He agreed with Major Mayo, however, that if they could save any weight in that direction it would be wise to put it into the detail fittings. The majority of their failures were confined to junctions, fixings, and so on, and if we were to produce really reliable aircraft they must design those parts more robustly than they had been designed in the past.

Mr. DIGBY: Commenting on the statement that British machines which entered America had to be stiffened up considerably in order to comply with the regulations, said it was only fair to add that machines entering this country from others had sometimes to be stiffened up. The American requirements in regard to inverted flight were far less than the British; they were something like from 40 per cent. of the C.P.F. factor, as against 60 per cent. in the case of the British.

Mr. W. E. GRAY (*contributed*): The present Certificate of Airworthiness requirement of a minimum rate of climb discourages slow-speed machines, and he would like to ask the lecturer if he can throw any light on the relationship between speed and human danger. The work done in injuring the occupants in a crash is probably roughly proportional to the kinetic energy, but the seriousness of injuries increases greatly with their depth; the risks may therefore go up as the cube or fourth power of the speed. Thus the certificate requirement deliberately encourages danger by encouraging power and speed. Speed is an important asset to flying, but even though nine out of ten people want to reach the next world as quickly as possible, it does not follow that the tenth should be forced to fly a similar machine.

The slower machine with the steeper climb path is denied a Certificate of Airworthiness though it is safer than the fast one; if the paths were identical, the slow one would still be safer as it gives one more time to think and act, and both can do identical manœuvres. Though the engine of the slower machine has more time to fail in getting to a given height in taking-off, yet the machine can be landed in a smaller area. Furthermore, speed and power put prices up and so prevent more people flying.

The lecturer refers to the protection afforded by the law, but its one legitimate function is to prevent people hurting others—not to save them from themselves. Nor is the good name of British aircraft a tenable object of the law—it is no use Savile Row complaining that the Strand is lowering the standard of British tailoring.

Might he suggest that in statistics of accidents it might be useful to express distances in equators instead of thousands of miles, as conveying a clear picture at once to the mind; miles are so short and light-years are beyond our hopes, but " equators " of 25,000 miles seem appropriate to aviation.

Lastly, he would suggest that a " home " Certificate of Airworthiness would be a useful innovation, one that would not be available for international flying (which only a small proportion of private owners wish to do) and would not come under the Convention. The climb and other requirements could therefore be easily varied in accordance with the teachings of experience.

Dr. ROXBEE COX (*communicated*): If Mr. Howard's estimate of the accelerations and high speed of multi-engined passenger aeroplanes is substantially correct, it might at first sight appear that very considerable reductions in the load factors for such aircraft might be possible. Reduction in strength, however, must generally be associated with reduction in stiffness, and it is, he thought, necessary to define a low limit for stiffness as well as a low limit for strength if the latter, as a result of the accelerometer and speed data which Major Mayo has told them are to be collected, leads to an appreciable reduction in strength requirements.

There are several characteristics of the aeroplane affecting its airworthiness which depend on stiffness and not on strength. Examples which immediately come to mind are the influences of wing stiffness on critical flutter speed, and on diminution of aileron control. It is to be hoped, therefore, that while the acceleration and speed records necessary for the reconsideration of the load factors for normal category aircraft are being collected, it may be possible to collect information on stiffness as well.

Mr. Howard has pointed out that it is highly probable that at present we have got our normal category aircraft too strong. Possibly also we have them too stiff. He suspected, however, that their stiffness factors may not be in fact so high as their load factors, and this aspect of the problem needs careful consideration.

The PRESIDENT: There appeared to be no doubt in the minds of those attending the meeting that the existing regulations required a certain modification, and it was very satisfactory to hear from the Director of Technical Development that there was a possibility of such modification taking place. It was to be hoped that the discussion, besides clarifying the position generally—as he believed it had done—would also serve to help Air Commodore Holt in framing the modifications he had in view.

REPLY TO DISCUSSION

Mr. HOWARD: Commenting on Sir Sefton Brancker's reference to the number of collisions which had occurred, he said that perhaps the figures in the paper were misleading. They included all cases in which a portion of an aircraft had come into contact with anything on the ground when taxying, and in many cases the accidents recorded were of quite a minor character. Mr. Handley Page had mentioned the nose-dive condition, and the point he had referred to was an old thorn in the flesh of the manufacturers. It was being considered very carefully, however, and he believed that revised proposals would be put forward for certain types of commercial aircraft. With regard to the pilot's view, mentioned by Captain Balfour, he said there were no hard and fast rules as to what was a bad or a good view. It was simply a matter of what Martlesham or Felixstowe thought about each particular aeroplane; if they thought it was bad it was bad, and something had to be done about it. His personal feeling was that that was a very healthy state of affairs, because the opinions of those at Martlesham and Felixstowe were of very great value, and the introduction of complicated rules about angles of view, blind areas, and so forth, would make things worse rather than better.

Discussing the plea made by several speakers that the regulations should be relaxed and that there should be freedom from control, he said that the position was that the Air Navigation Acts existed, and the Air Ministry had the task of ensuring that they were complied with. Until those Acts were repealed this duty would remain, and he could hardly discuss the question of whether or not there should be control of civil aircraft. As Major Buchanan had suggested, if there were no Government control there would probably be control by insurance companies, and the industry might find itself jumping out of the frying pan into the fire.

Commenting on the remarks of Mr. Douglas with regard to the difficulties of the strength test system of approval, he said that many were familiar with the very exact and careful methods of strength testing which Mr. Douglas carried out, and they were of a type quite different from the strength tests applied in many cases for approval. Speaking with caution, he said the impression he had gained, as the result of reading accounts of routine tests made in foreign countries, was that the testers did not take the same number of measurements that Mr. Douglas took; load was simply applied until the structure collapsed, and there were no records taken as to when failure began, when a crack was heard, or as to creeping, and so on. A strength test by Mr. Douglas resembled rather a scientific experiment.

With regard to Major Barlow's remark that he did not see why the Airworthiness Department should be interested in how the safety belt was attached, and that it was not necessary to go into such detail, he said he could give fairly definite evidence that it was necessary to take an interest in that, because safety

belts that would come adrift were being used and people were being injured as a result.

He did not quite follow Mr. Radcliffe's suggestion that our factors were based on a factor of safety of one and one-third, and did not entirely agree that our factors were based on a factor of safety. He had always rather opposed the division of our load factor into two halves. Commenting on Mr. Radcliffe's reference to the different methods used in the different countries, he said this country had always suffered from the fact that the actual number used to denote the strength was low as compared with the numbers used in other countries. We made a number of pessimistic assumptions and calculations, which meant that the number we used was low, although the strength denoted thereby might be as high as that denoted by larger numbers in other countries.

He disagreed with Mr. Bramson's suggestion that the Certificate of Airworthiness did not guarantee airworthiness. If a design had passed the tests at Farnborough and at Martlesham Heath, there was fair evidence that it was airworthy, and he did not think that anything really dangerous was likely to get through with our present methods of supervision. He disagreed strongly with Captain Balfour's suggestions that the pilots at Martlesham Heath had not commercial minds, were not very much interested in civil aircraft and regarded the business as rather a nuisance. The pilots at Martlesham Heath, he said, were very careful and conscientious in their treatment of civil aircraft; they were interested in the development of civil machines, and gave as much attention to the tests as they did to Service tests. Actually trial by Service pilots was a very valuable feature of the airworthiness investigations, and their criticisms of the designs were very valuable; he believed most designers would agree that such criticisms had helped them in their later work, and that many improvements had been effected as the result.

In reply to Dr. Roxbee Cox, I am in agreement that in reviewing standards of structural strength the flutter question must be kept in mind. One can only hope that by the time the accelerometer data for this purpose becomes available we shall be in a position to avoid flutter without recourse to the wasteful expedient of unnecessary strength.

In reply to Mr. W. E. Gray, I gave my views in the paper on the adequacy of our present take-off requirements. I had in mind precisely the point raised by Mr. Gray. It might be noted that the continuation of the barrier test and the time to height test does in practice place a lower limit on the angle of climb.

The suggestion of a " Home " Certificate of Airworthiness would lead to great administrative difficulty and general inconvenience. It is hardly ever possible at the stage when an aircraft is granted a Certificate of Airworthiness to predict its ultimate use

BRANCH LECTURES

SOME TECHNICAL NOTES ON CANADIAN AVIATION

BY

SQUADRON-LEADER D. C. M. HUME, R.C.A.F.

(*Lecture delivered before the Yeovil Branch on November 11th*, 1929.)

Before opening my subject let me explicitly impress upon you that any opinions I may be found to have expressed in these notes are purely my own, and not necessarily shared by the Service to which I have the honour to belong, much as I owe them to its inspiration.

General Canadian Conditions

To appreciate the problems of Canadian aviation it is necessary to obtain a grasp of the general conditions of this great section of the Empire—3,000 miles wide and a thousand deep—fraught with such vast Imperial possibilities.

Canada is divided by Nature into four main tracts:—

(*a*) The Western Tract, which lies between the Pacific seaboard and the Canadian Rockies. This area has a climate which may be visualised as super-English, *i.e.*, damp enough to be mellow and very fertile, and sunny enough for intense vegetation and year-round open weather. This tract contains British Columbia and is a well mineralised and heavily timbered country containing a deal of inland water.

(*b*) The Central Tract, running from the Rockies to longitude 100°, *i.e.*, near Winnipeg, embraces Alberta, Saskatchewan and Manitoba Provinces, and is the Prairie District, the Grain Garden of the Empire. The climate here is dry and subject to big winter-summer temperature variations. It is windy, flat, bald country with very little inland water; its mineralisation is probably very vast and valuable.

(*c*) The Eastern Tract, running from longitude 100° to the Atlantic, embraces Ontario, Quebec and the Maritime Provinces, and owing to its geographical position and historical past it is the commercial and Governmental focus of the Dominion. The climate in this area is invigorating and again dry, though less so than the Central Tract, and is subject to seasonal temperature limits of the order of 90°F. summer shade to 30°F. below zero of winter. The area is thickly timbered and strongly mineralised, and contains Canada's two largest cities, Montreal with a million and Toronto with three-quarters of a million inhabitants.

(*d*) The Northern Tract caps, as it were, the other three from Yukon Territory to Labrador. The climate is sub-arctic and what it may contain for the adventurous pioneer only the immediate future and the aeroplane can solve.

Uses of Aircraft in Canada

Apart from purely military uses of aircraft, which uses probably reach their minimum among nations in Canada, the uses of aircraft in Canada may be catalogued conveniently in the main in reference to the above defined tracts:—

(*a*) *Western Tract.*—Fish (salmon) preservation and distribution, smuggling and prevention, forest fire patrol, survey photography and air mail. Prevalent type of aircraft—seaplane.

(*b*) *Central Tract.*—Survey photography, crop dusting, air mails, prospecting. Prevalent type of aircraft—landplane (wheels and/or skis).

(*c*) *Eastern Tract.*—Survey photography, timber cruising and forest fire patrol, prospecting and passenger work, and air mail. Prevalent type of aircraft—convertible sea-landplane with skis and/or wheels.

(*d*) *Northern Tract.*—Prospecting so far only dominating use pending further development of this area. Prevalent type of aircraft—cabin landplane (wheels and/or skis).

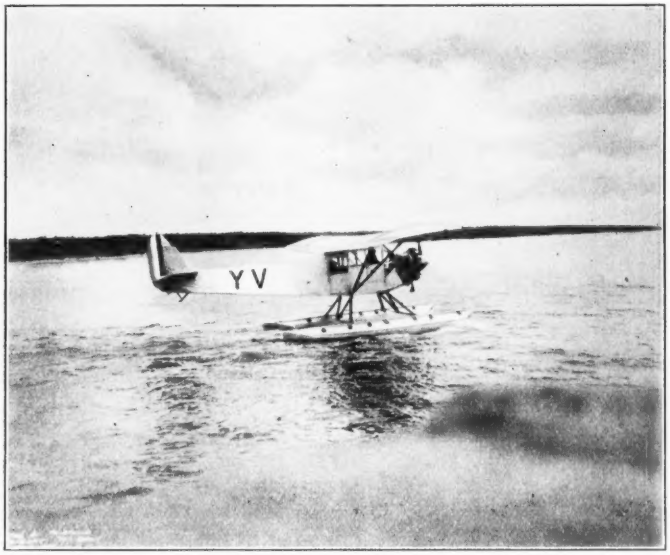

FIG. 1.

Fairchild-Wright, used for photography and mail route breaking.

Space confines any detailed description of the above uses, but it is well to mention that the mineral resources of Canada are vast and varied. There is gold, silver, nickel, aluminium, lead, asbestos, bituminous sands and coal, and what may yet come to light no one can foresee. In organised commercialised prospecting for minerals the aeroplane is playing an ever increasingly important part.

In the wake of prospecting comes the need of good maps, and in the mapping of Canada the aeroplane is man's most profitable ally. For the last six years organised mapping has been carried on by the Royal Canadian Air Force for the

Topographical Survey Branch of the Department of the Interior, and as a gauge of the work done the files contain 254,000 individual prints of which 92,000 were taken in 1928 alone. Yet the mapping of Canada north of the C.P.R. Trans-Canada line has only been nibbled at, as yet; this huge area is being filled in, bit by bit, entirely by air photography.

Canada's great wood pulp industry depends upon the preservation of its forest stands of timber whose main enemy is fire. A forest fire allowed to run its course may easily destroy an amount of timber, the value of which would pay many times the cost of a year's air patrol that could have prevented it. The Provincial Government of Ontario has so far absorbed this fact that it maintains

FIG. 2.
Forest lands in Quebec.

a large air service of its own to protect the provincially owned forests from the fire fiend. The value of air fire patrol lies in the speed with which fire can be spotted and reported. A young fire can be killed by man, only Providence can kill a full-grown one.

Informative experiments have been made on dusting from the air to defeat fungoid and insect pests such as produce wheat rust, white pine blister rust, etc. Results are encouraging. Dusting with sulphur, for instance, is done at the rate of 500 lbs. in 15 minutes at 25 lbs. the acre. Other uses of aircraft mentioned in the list above are self-recommending.

From the uses enumerated and their value and need it is seen that, leaving passenger-carrying and air mail aside, Canada is in the unique position in the civilised world of having a "job of work" waiting for the aeroplane to do, thus supplying an automatic air education for its people and a productive form of indirect subsidy for its industry.

The Royal Canadian Air Force's Part

Aviation has been fostered since its inception in Canada by the pioneer and later development work of the Royal Canadian Air Force, which work has been ably consolidated and furthered by the forces of commercial adventurers now rapidly crystallising into a corporate industry.

Canada being a peaceful country with no domestic war hazard is only war organised to take her proper place when Empire need arises. The military character of the R.C.A.F. is therefore its least obvious; its principal activities appear in the Directorate of Civil Government Air Operations, an organisation manned by the R.C.A.F., and run by the Department of National Defence to do as the name implies, Air Operations for other Government departments.

The military branch of the R.C.A.F. trains all service pilots and the Directorate of the C.G.A.O. uses most of them. The latter directorate is military in composition and commercial in effect. The dual functions call for a dual policy of equipment. War types are kept essentially the same as the English R.A.F. Civil types are built or bought to suit local conditions.

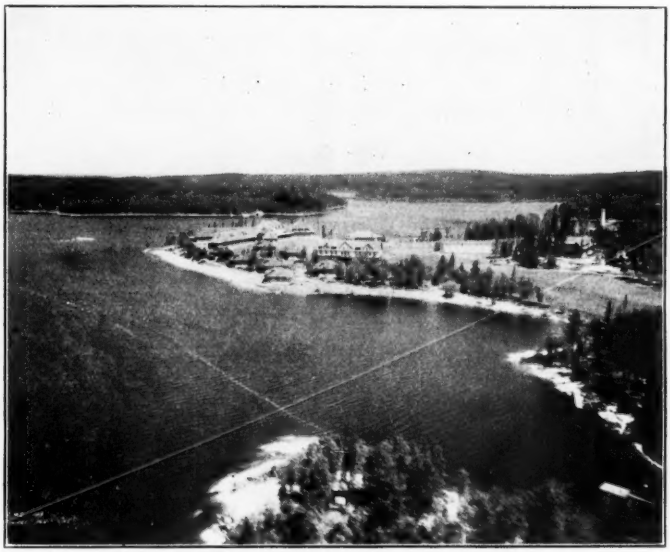

FIG. 3.
Typical Ontario country.

Peculiar Problems

With this picture before us as to the lie of the land, the work to be done, and the machinery to do it, we can proceed to detail some of the problems peculiar to the task. The problems classify under three headings:—

(*a*) The adaptation of the aircraft to conditions of climate and country, and

(*b*) The adaptation of the aircraft to the specific work required of it, and

(*c*) They may be further classified as they affect air frames, engines and actual flying.

Problems of Climate and Country

1. *Air Frames.*—The large seasonal and geographical changes of temperature and humidity affect all wooden and mixed structure frames.

Shrinkage is great between districts, and if combined with a seasonal change, may be excessive. As an extreme case may be quoted D.H.9 wings built in England of English seasoned lumber, which broke every rib after shipment to dry Alberta. Canadian spruce seasoning practice is to dry in air in the pro-

FIG. 4.
Canadian Vickers Vidette.

tected open for two years and finish with indoor seasoning in a chamber the humidity of which can be controlled to give the specification moisture content to the lumber.

It is interesting to note here that it has been found economic in the past, owing to the vastness of the area supplied, to centralise and thereby standardise

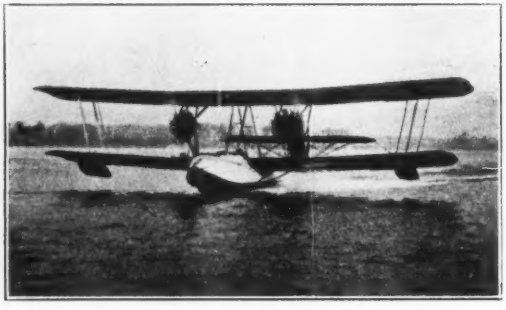

FIG. 5.
Varuna Vickers.

inspection of lumber, and also the cutting; thus only inspected, proud-cut lumber is shipped, and the throw-out concentrated and its cost of transport saved.

Seasonal temperature variation of the order of 90°F. in summer to 30°F. below zero in winter can produce rigging distortion in mixed structure frames.

Plywoods and planking are apt to suffer at both ends of the scale. Water-soaked lumber or finished wooden parts are ruined if the contained water freezes.

Blue stain rot in spruce needs watching, especially in seaplanes where, under summer temperature drenchings and heat, bacteriological cultural conditions are good. Certain glues assist bacteria and moulds, and fungi are readily formed in damp unfreely ventilated places.

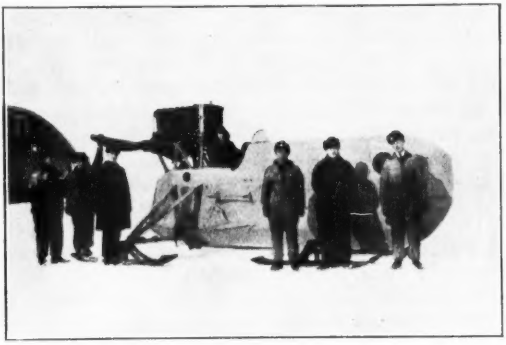

FIG. 6.
Winter crash wagon, fitted with skis.

Canadian climatic conditions do not produce any marked deterioration on properly doped surfaces within the overhaul periods of aircraft. Nitro-cellulose dopes are used exclusively on Canadian aircraft.

Evidence of low temperature fatigue of metals is very indefinite and slight, and may be taken to be non-existent in practice. The all-metal air frame is the present day requirement, provided it is made on a simple system and simply replaceable in need.

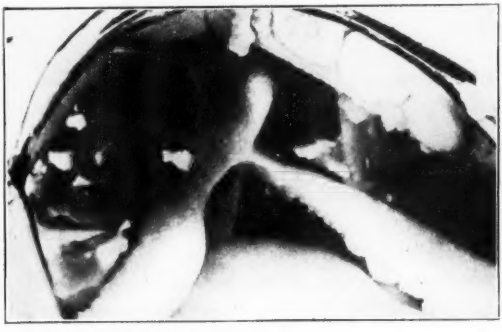

FIG. 7.
Hudson Straits Express, snow in cockpit.

2. *Engines.*—Until the economic air-cooled engine became available water-cooled engines had to be employed in Canada with their attendant obvious drawbacks in sub-freezing conditions, and their large weighty radiator system in summer semi-tropical heat.

Freezing can be avoided by:—

(*a*) Draining off the cooling water when not flying, a cumbersome, inconvenient process, and one likely to leave ice pockets in the cold engine, or pumping system, which produces fractures with ease.

(*b*) Covering the engine unit with quilted engine covers and using some local heating unit during stand-by hours, such as catalytic lamps or electrical immersion heaters. This process is not quite good enough for sub-zero conditions, and the electric heater, whether immersion type or jacketting type, can and has produced a fire in the aircraft.

(*c*) Covering the engine against the heat radiation of strong cold winds and using an anti-freezing compound in the water. This arrangement is the best of the three. Of anti-freeze compounds, the best (*i.e.*, the lowest setting) is an admixture to the water of 40 per cent. alcohol, the only practical disadvantage of which is its liability to evaporate off the spirit. This loss of anti-freezing protection was defeated by a simple "gadget." The normal overflow drain of the radiator was stopped up and substituted by a copper pipe led from the filler neck through half a dozen coils exposed to the cold air of the slipstream into a metal container which it entered at the topmost part and inside of which it extended to almost the bottom. When the alcohol began to come off it was condensed by this device into the metal container whence, upon the engine cooling off after flight, it was sucked back into the radiator and thus retained. Not more than 5 per cent. loss in a month was experienced when using this device.

In cold weather engines get cold enough to freeze any condensed water in the cylinders, and therefore it is expedient to take out all spark plugs and keep them in a dry warm place between flights.

Oil troubles have been solved in recent years by knowledge of mixing and choosing of suitable grades, and the absolute necessity of draining between flights and refilling with warm oil when required has been largely obviated, except in very extreme conditions. Mixtures up to 6 to 1 of such oils as Mobile Arctic and B.B. grades will cover the range down to 30°F. below; if the oil has been left in the engine, the engine must be "limbered up" by doping and turning, whilst if a bye-pass thermostatic device be fitted to the main supply of oil, so much the better, and excessive pressures and starvation of supply will be avoided.

Cold weather starting has been of necessity studied in Canada and a simple technique evolved. Sub-zero starting can be effected in general in one of two ways:—

(*a*) From stone cold conditions by doping with definite charges of a specific volatile mixture, or

(*b*) By temporarily heating the engine combined with straight doping.

Process (*a*) is the result of a series of experiments carried out at Camp Borden, Ontario, and more intensely by Professor Robb in association with the R.C.A.F. at Edmonton University, Alberta, in the winter of 1925-6. The complete technique is:—

(*a*) Ease the engine by doping freely with half a pint of petrol. (If the engine be water-cooled, the start is made with the cooling system as yet empty of water.)

(*b*) Dope the engine with a quarter of a pint of petrol-ether mixture. *Note.*—This amount must not be exceeded.

(c) Turn the engine for a start; as soon as it starts to fire dope an additional quarter of a pint of petrol-ether into the in-take manifold. This should start the engine running normally on petrol, especially if the carburettor be flooded. (If the engine be water-cooled run it for two minutes and then put in the water. *Note.*—Premature boiling will indicate an ice pocket in the system.)

In this routine the priming nozzles need to be large and need to be watched for freezing up. The usual dope pump is inadequate, and the experimenters used a grease gun 1¼in. bore and 7in. stroke. With regard to the precise petrol-ether mixture, the following are recommended:—

Ground Temp. °F.	Petrol.	Ether.
Down to +20° ...	All	Nil
+20° to 0°	3	1
0° to −15°	2	1
−15° to −30° ...	1	1
−37°	Nil	All (at room temperature)

A throttle opening of 20 per cent. was used in these starts.

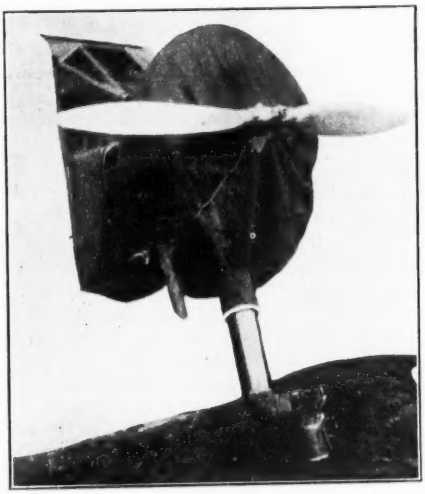

FIG. 8.

Hudson Straits Express, method of heating engine.

Process (*b*) was employed by the Hudson Straits Expedition of 1927-28 with great success, using Wright Whirlwind air-cooled engines. An asbestos bag or hood enveloped the engine and a trunk-like tubular duct depended therefrom to the ground and terminated in a length of seven-inch stove pipe elbowed at its lower end, and fitted with a gauze diaphragm. The only exit from the bag is by way of the engine cylinder fluting, aft.

Into the mouth of the tube was directed the hot blast of two blow lamps. A possible refinement suggests itself here in arranging a bell-mouth to the tube and obtaining an injector action to the air feed.

This heating process took some thirty minutes and during that period the engine was turned periodically both to assist and ascertain the suppleness achieved. At the end of half an hour hot oil was put into the engine and a normal start effected. This technique was employed in Arctic conditions, where it was found necessary, it is interesting to note, to use an oil mixture of five parts of " Arctic " grade oil to one of medium grade oil.

Coming down to conditions of comparative warmth, say +5°F., the following starting routine has been employed with success on Jaguar Siskins in Canada :—

(*a*) Switch off.
(*b*) Turn the engine six times with the throttle half open.
(*c*) Give one good stroke of the standard dope, pump each half turn of the engine. *Note.*—Petrol should drip from the exhaust ports of the lower cylinders.
(*d*) Switch on and turn the hand-starting magneto smartly when the engine should start.

It may be observed here that it is an assistance, if not a necessity, if all exposed oil pipes, especially those in the slipstream, be lagged as also should be the oil tanks. Fireproofed hair felt is suitable for this latter purpose.

All forms of engine starting are greatly helped if some form of inertia starter is employed. This device is practically standard equipment on Canadian aircraft to-day.

A winter starting device used in the U.S.A. services in the comparatively warm winters of North Michigan consists of the sprinkling of ether on a hot brick held in the vicinity of the engine air in-take. I have, however, seen this fail hopelessly in a temperature of 20°F. below when nothing short of a steam thawing plant, as used in Canada to keep fire hydrants serviceable, would start a 400 h.p. water-cooled engine.

Winter carburation as such presents no unusual problems, but air in-take scoops are advantageously arranged facing aft, especially in seaplanes, to avoid spray, ice and snow troubles.

Before leaving the question of engine problems peculiar to climate conditions mention should be made of the fact that the well-known anti-knock device of using benzol mixture is not possible in Canada because either the vapour of benzol freezes in use or the benzol mass freezes out solid and cannot be readily and easily thawed out. In these circumstances tetra-ethyl-lead has been resorted to, formerly at the rate of 5 c.c. per gallon, which has latterly been reduced to 3 c.c. The only trouble experienced with this chemical was a deterioration of aluminium bronze valve seats apparently attributable to its use as the substitution of special steel seats gave no further trouble, though their use was combined with the reduction in the ethyl content.

3. *Flying.*—Problems arising from the act of flying are mainly concerned with getting off and alighting from the various kinds of surfaces the country provides, but before passing on to this group mention may be made of a control designing need very easily overlooked. During periods of the year when big temperature swings may be encountered even diurnally and during just before and after the ice forms, the machine and engine controls may, if precaution be not taken against it, become frozen up immovable during flight. Cases are known of seaplanes, still in use as such from yet unfrozen rivers, having had their controls and lower wings locked solid with frozen spray, and aircraft flying through snowstorms which are usually comparatively warm have met with similar difficulties on emerging into colder air.

In the matter of getting off and alighting the main summer flying peculiarity needed in Canadian aircraft is greater initial climb and quicker get off than the

actual duties engaged in may demand. This arises because it may be that the craft have to land on and get out from a small lake not conveniently oriented to the wind of the moment, and having standing timber 50 feet high growing right down to the water's edge. Analogous characteristics will be required in aircraft subject to ravine flying in mountainous districts, where not only are high initial altitudes to be met with, but more than normal climbing ability is needed to defeat down currents from the ridges round the ravines. As a guide the get off required is of the order of 15 seconds or better with as high a rate of climb as other specification requirements will allow.

Another provision to all seaplanes for Canada is one of some sacrifice of weight in all flotation components to look after the natural hazards of Canadian waterways and the variety of bottoms upon which it will be found necessary from time to time to beach. Many rivers of Canada are used for logging in connection with the pulp industry and a proportion of the logs floating down become water-logged and sink by one end, stick in shallows and become a very present danger to landing seaplanes if not spotted, and additional sturdiness is of assistance if bad wrecks are to be avoided.

The majority of getting off and landing problems arise during winter flying. Except in conditions of very thin snow, which are short-lived, wheels are useless in winter flying. The solution is the employment of an efficient ski gear.

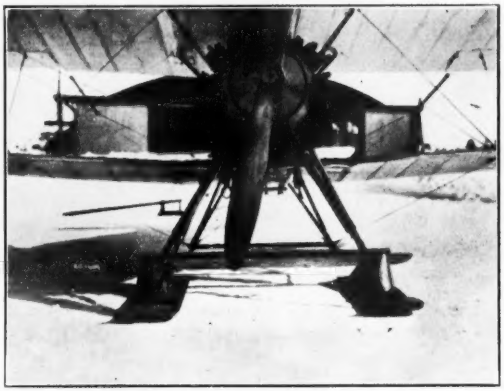

FIG. 9.
Siskin skis stays offset for support.

Winter Alighting Gear

The ski gear has been in process of evolution for some years past. It is an elusive problem to design skis that combine efficiency on all classes of surfaces, cheapness, lightness and sturdiness, and it does not lend itself to precise theoretical treatment, being largely empirical as to its data.

There are three main classes of winter surfaces found in Canada, though they may be blended diversely daily, they are:—

(*a*) Glare ice, such as wind-swept surfaces of frozen lakes or rivers.
(*b*) Packed, frozen and crusted snow.
(*c*) Soft snow.

Virgin snow in Canada is for the most part dry and dusty in form, but it will pack under surface loading, wind forces and drifts and subsequent overlays of snowfall.

(*a*) *The Chassis.*—To look after landings on these varied surfaces and combinations thereof, the requirements of the chassis are not dissimilar to those for landing on hard ground, and a shock-absorber gear is required, for even if condition (*c*) above may not exercise it, condition (*a*) certainly will. Rubber shock-absorbers are no great use in sub-zero temperatures, but any good oleo undercarriage will satisfy with the minor modification that the oil in the oleo leg must have a lower setting point than that usually employed, and a mixture of 20 per cent. paraffin or coal oil, as it is called in Canada, and 80 per cent. Mobile A, which sets at around 40°F. below, has been found satisfactory.

(*b*) *The Ski Support.*—It being desirable, in view of the suitability of a land chassis, to have skis interchangeable with wheels, they have to be mounted or supported from the wheel axle tubes of the chassis. Supports based on this fact have been evolved from a plain pyramidal structure of wooden struts through braced and tubular variations of this to a conical metal pot, like an inverted coal bucket, having a more or less streamline horizontal section and internally

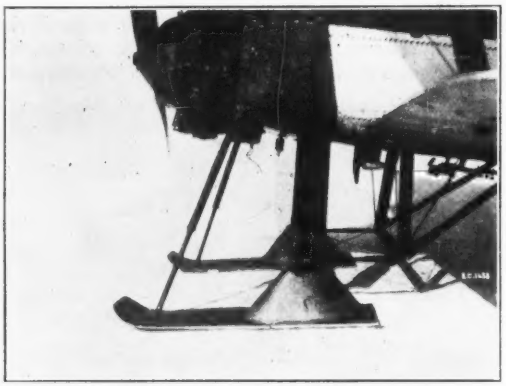

FIG. 10.
Siskin skis, later pattern.

stiffened by lightened bulkheads. The " pots " are of 12 gauge duralumin and are designed so that the load is taken by the skin and not the stiffening frames, as a lighter construction can be achieved in this way. A trunnion bearing at the top of the " pot " accommodates the axle tube, and the support is held on by bushes, collars and split pins to admit of rapid removal in favour of replacements or wheels when desired.

(*c*) *Skis.*—The ski itself naturally started as an imitation of the human ski, and has evolved from a plain turned up wooden plank through successive stages of laminated planks, metal-faced laminated planks, corrugated all-metal skis, corrugated metal bottoms backed by wooden laminated fillings to the latest pattern which is a flat-bottomed duralumin faced laminated wood ski fitted with two (or even one) fore and aft runners.

Without detailing the experimental work in the past, but making reference in passing to two contributions to the Royal Aeronautical Society's JOURNAL by Wing Commander E. W. Stedman, O.B.E., R.C.A.F., it may be helpful to describe the requirements of a modern ski for an aircraft of say 5,000 lbs. all up weight.

Firstly, such a ski will have a surface loading of 200 lbs. per square foot. A higher loading tends to make the aircraft difficult to move from rest, for the

tendency of a ski to freeze to snow is roughly in proportion to the depth its borne weight causes the aircraft to sink on its skis into the snow.

Secondly, the cross section of the ski will be convex transversely. This shape avoids the tendency of the ski to dig in on a side wind landing or surface skidding.

Thirdly, the bottom will be flat, which feature keeps the snow contact as small and clean as possible. The large contact surface of corrugated bottoms was one of their derogatory features. The bottom will be faced with a light, tough planished metal, both for protection and to keep the coefficient of friction low. This bottom will have a central small metal keel on strip to give directional stability and restrain side slipping when not desired.

Fourthly, the fore end of the ski will be turned up about a radius of some eighteen inches, in order to help the snow ploughing action of the ski in taxying, and its general riding virtues when alighting. The rear end of the ski will also be turned up slightly, but decidedly, to prevent " snow shovelling " when manhandling the aircraft astern.

Fifthly, the complete ski with pot support, described previously, ready to fit on the wheel axle will not weigh more than 90 lbs.

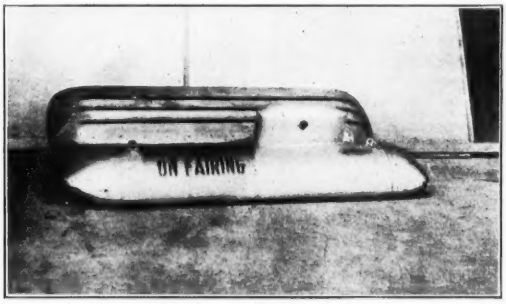

FIG. 11.
New type Moth ski.

All that now remains is to keep the skis at the required angle of trim fore and aft when in the air. This angle is that at which negative lift on the ski is a minimum when the aircraft is flying at fine angles of attack and a convenient general setting figure is $+2°$ to the wing chord.

There are one or two methods of restraining a ski in the vertical plane, the simplest being by means of " tilt cables " fitted to the toe and heel of the ski, the upper ends being attached to a convenient place on the air frame. These cables have a mid portion of shock absorber rubber to provide the required degree of rotation of the ski on landing, taxying, etc. Tilt cables have to be kept clear of propellers, as they may thrash into the blade circle.

A second method is by means of trimming legs, one of which only is needed per ski as against two tilt cables, which are streamlined telescopic double acting spring struts between one end of the ski and the air frame. This device is good where cables are impracticable, but trimming legs are apt to be expensive and, being long for their essential diameter, frail; their chief part is concealed, and if they are at all excessively off-set from the vertical, they may bend and stick under the shock loads.

A third method which shows promise, but is as yet young, employs some self-contained springing device in the ski support itself, such as a spring loaded

leverage anchored on to the aircraft axle. This has the merit of being protected from casual damage and of being fairable with the ski support.

An attempt has also been made recently to give skis a limited spring-restrained rolling movement about their own fore and aft axis, in order to relieve off-set loads on axles in landing, especially with split undercarriages.

Ski designing has, like much excellent research, been largely a process of intelligent guessing from empirical data. Trial and error produced a workable surface loading, but given an indicative figure this varies as the reciprocal of the power loading of the aircraft for :—

$$u = kW/A$$

where u = coefficient of friction between ski and snow.
W = total weight of aircraft.
A = contact area of ski system.
$R = uW = (kW/A)\,W$.
where R = resistance to tractive effort T.
$T = K$ h.p.

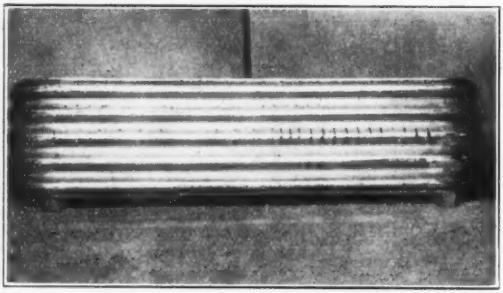

FIG. 12.
Fairchild-Wright ski.

Therefore, for motion to commence

$$K \text{ h.p.} = (kW/A)\,W$$

$W/A = K$ h.p.$/kW$, *i.e.*, ski loading = constant/aircraft power loading.

Note.—The contact area of the skis is the total length of skis less the turned up portions at either end.

The disposition of skis relative to the aircraft is decided by the mechanics of turning on skis. A turn is a spinning sideslip by the main skis generated by the side tracking of a steerable tail ski. It is to give it a human parallel like a man with three legs doing a Christiania turn with two of them and a steered turn with the other. The weight has therefore to reach the snow surface a little behind the centre of side resistance to skidding if the skis are to turn as well as skid.

In practice it has been deduced that with skis of aspect ratio of 1 to 4, a value induced by the need of keeping the ground below the propeller circle clear of obstructions, the axle is well placed if it be so that its height above the snow surface is just in excess of its vertical distance behind the line of side resistance. Some such position is also indicated by the direction of the resultant of the force of forward motion and the weight of the aircraft and the above 45° location fits most cases.

Tail ski design is at present purely empirical. On an Avro, for instance, the wooden tail skid is faced with a small spatulate ash facing of similar contour and some ten inches wide.

Before leaving winter flying problems the method of " pegging down " aircraft in snow or on ice may be interesting. In place of pegs empty sandbags are taken and gathered about their centres to a waist around which is tied a mooring line or fitted a clevis. At the appropriate place in the snow beneath the mooring eye on the aircraft is dug a hole and the sandbag is dropped into it, after which water is poured in and snow packed on. The result is a frozen-in block. The aircraft is thus " frozen down " and will never shift.

The trend of these notes seems to stress the winter flying as characteristic of Canada. That is a misconception. The chief and more unusual problems, especially to English ideas, naturally occur during winter conditions, but by far the greater air mileage is made in the glorious summer of our Golden Dominion.

Problems of Specific Duties

Aircraft operating in a vast country on such duties as fire spotting and photo survey are apt to be away from their base for long periods, and their structure must therefore be sturdy, simple, easily maintained and repaired, using as few varieties of standard and as few special parts as practicable.

FIG. 13.
Hudson Straits Express.
Changing skis to wheels.

S.A.E. standards are preferable in non-military aircraft, as items made to them can be obtained more easily in Canada than B.E.S.A. standard items.

Floats and hulls need to be sturdy as they will assuredly, if unintentionally, be banged about in uncharted shallows and rocky shore line moorings. Amphibian gear is useful more by virtue of its trolley substitute feature than its true amphibian uses, but is a weight wasting device on an aircraft of already generous structure weight.

Float seaplanes are best handled by wheels and axles passed through the floats by the wading party, but in other cases independent dollies are preferred to large single trolleys or tied twin dollies.

Mention has been made of dusting work above, and it must be remembered that some of the dusting agents, such as sulphur and arsenical compounds, are apt to make corrosive chemicals in contact with salt water. This must be guarded against in designing all metal floats. One of the most virulent cases of pock pitting and general corrosive perforation occurred on the duralumin floats of an American seaplane used at a seaside station for but half a season. The floats were fitted with new bottoms of alclad, but I have no information of their subsequent behaviour.

Metal propellers are the choice of all Canadian Air Services, and a type using a split steel boss with adjustable blade settings is preferred. Not only does the inherent ruggedness of metal propeller appeal, but intelligent selection of engine patterns permits of very few blade forms being carried to cover a number of duties; the adjustable setting can, for instance, be advantageously employed in changing an aircraft from floats to wheels.

The use of inertia starters for engines is more or less universal, and is a great advantage in small crewed craft and single-handed starting of twin-engine aircraft. If not over lubricated these devices are quite satisfactory.

Problems of general aircraft design as affected by specific duties in Canada might make a treatise in themselves, so let it suffice here, if I give an epitome of the present day requirements for an aircraft to carry out Canadian Civil Operational Duties as follows:—

(*a*) The aircraft will accommodate both oblique and vertical photographic apparatus, preferably from the same camera.

(*b*) Personnel—pilot, navigator and photographic-mechanic. All three require perfect view ahead, and at least two of them must get it.

(*c*) A closed-in, heated cabin for all personnel is desirable, if it does not interfere with the requirements of (*b*).

(*d*) Duration—one hour at sea level and five hours at 10,000 feet is the minimum of interest. Vertical photo survey is conducted at 10,000 feet for the most part and oblique at 5,000 and over, and although the total number of flying days in Canada per year is high, the ideal photographic days with no ground haze or intervening clouds are few enough to cause considerable flutter when they occur, so that the duration quoted is not unreasonable.

(*e*) The aircraft will be usable as a seaplane, landplane and snowplane, and be quickly and simply interchangeable from one to the other.

(*f*) The engines will be air-cooled and be fitted with an easily operated turning device and adjustable blade airscrews of metal.

(*g*) The airframe will be all metal in construction.

(*h*) The total borne load, excluding fuel and oil, will be 1,000 lbs.

(*i*) The aircraft will have a surface ceiling of 15,000 feet.

The Canadian aircraft of the future is less easy to define save that if it is not a true amphibian it will have to be able to land on grass or snow at will, as it is often possible on routes such as Montreal—New York or, nearer home, Ottawa and Toronto, to leave the one end covered in snow and land on bald grass at the other.

In conclusion, a few sample statistics of Canadian aviation may serve to give a more vivid picture of the extent to which our problems have to be applied, and therefore of their importance, as well as impress the prominence to which aviation has attained in the largest single area of the British Empire.

Civil Air Statistics

	1926.	1927.	1928.
Aircraft Miles	393,103	829,010	2,728,414
Freight carried (lbs.) ...	724,721	1,098,348	2,404,682
Mail carried (lbs.) ...	3,960	14,684	316,631
Air Miles of Accidents ...	78,621	207,252	151,579

Some further figures covering 1928 from R.C.A.F. flying only are of interest :—

Acres covered on fire patrol, 1928 ...	64,534,563
Fires spotted	187
Air hours logged	6,061

The total strength of the R.C.A.F. is but just over 1,000 men of all ranks.

Making an estimate of the air miles flown by the R.C.A.F. whose returns are not made in that unit, the total air mileage of Canada for 1928 is nearly 3,000,000.

THE SCHNEIDER TROPHY, 1929

BY

FLT.-LIEUT. H. R. W. WAGHORN

Lecture delivered before the Yeovil Branch February 14th, 1930.

The first of the 1929 team to be posted for High Speed Flying was Greig, who towards the end of 1928 was sent to Calshot to make another attempt on the Speed Record. He achieved 319 miles an hour, which was the fastest speed on record, but did not exceed the Italian speed by a sufficiently large margin to count as a new record. While at Calshot, Atcherley and Stainforth joined him to start training, but very little flying was done during the winter months. Squadron Leader Orlebar took charge of the Flight when it was formed early in February, 1928, and I came a few weeks later. We had Moon as an engine officer, who had been with the 1927 team in the same capacity.

None of the team having been seaplane pilots, we started with the Fairey III.D., and Flycatcher, and then worked through the Gloster IV., Gloster IV.A., and Gloster IV.B. I don't think any of us found any jump from a land plane to the ordinary seaplane as from the handling point of view; they are really remarkably similar. However, our first flight in the Gloster IV. was a decided jump. The whine of a fast revving engine, the seemingly endless take-off with its attendant jolts and jars magnified in some extraordinary way; the difficulty of knowing what speed you are travelling at and the apparent magnification of any inaccuracy in flying, all helped in giving me, at any rate, a very vivid impression of my first flight in a high-speed seaplane. The Gloster IV.A and IV.B had been modified since the 1927 race and the top plane, instead of coming in line with the side cylinder banks, was raised and a centre-section fitted. This was done in order to give the pilot a better view, and while doing so set up another problem, for the centre section and header tank had apparently partially blanked off the fin and rudder, making her very unstable directionally. This was rather disconcerting on one's first flight and necessitated a lot of "sawing" on the rudder bar until one got used to it. This directional unstableness was cured, however, by having a non-symmetrical rudder and fin fitted above the centre line. Until February, 1929, there had been very little practice flying going on owing to bad weather, but after that the Glosters and particularly our old veteran, the IV., did quite a lot of flying. Early in April the Flight moved to Calshot, where we found the S.5, N.219 awaiting us and 220 was to join us in a few days. The transition from the Glosters to the S.5's was particularly easy and we enjoyed flying the Supermarines every bit as much as the Glosters.

As we put in a few hours practice in these high-speed machines we found that their peculiarities which had struck us rather in our first flight gradually faded away. Like all new sensations, you get used to them, and I will not try and give you my feelings when flying once the novelty had worn off. To start with, any feeling of g or acceleration is greatly exaggerated—a very slight movement on the stick back and you feel as if you were being shoved through the seat, and if, after a bit of a climb you inadvertently ease the stick forward too quickly, you feel as if no straps on earth will hold you in. Anyone who has flown will know the pressure of g in a tight turn or loop. Of course, this force is felt in exactly the same way, only instead of $3\frac{1}{2}g$ being the maximum anyone would normally think of putting on (and this would be considered uncomfortable), and

would need a heavy hand, such *g* in a high-speed machine is produced by a comparatively gentle movement of the stick. So it was we found we were easily subjected to big forces of *g*. This is one of the most noticeable things about high-speed flying. Some people have thought that forward acceleration would be terrific, and it has been seriously suggested in newspapers that the back-rest was to prevent pilots breaking their necks on opening the throttle. Never a more misleading statement, because the drag of the floats damps out any terrific acceleration at those speeds. At higher speeds the acceleration is comparatively slow. I have also seen it in print that a possible cause of the accident to the late Flight Lieut. Kinkead was the sudden deceleration of shutting the throttle made him fall over the stick of the S.5 and push it forward. I am sure this was not the case as I had the S.6 cut out through lack of petrol and although such a violent procedure made the engine whip in the fuselage, the deceleration was hardly noticeable. No doubt due to the perfect streamline. In regard to whether one gets a sensation of speed one can safely say that one does not, if flying at 200 feet or above. On the other hand, I personally think that at 50 to 100 feet one does very definitely get a sensation of speed, especially if flying alongside the coast. It does not, however, equal the sense of speed that 40 m.p.h. in a pair of skis will provide if any of you do any ski-ing. Once in the air the actual handling is identical with any ordinary aeroplane. All the machines we were flying had nicely harmonised controls and not in any sense heavy.

One of the first problems that confronted us was to find the most efficient method of turning. The type of big climbing turn in which the pilot gained a lot of height and then dived into the course was ruled out fairly early on; in fact, it was proved to be inefficient by the 1927 team. At first we thought that a completely level type would be best, but some of us thought that it would be best to let the machine climb very slightly; the reason for this was that, owing to aileron drag, there is a strong tendency for the machine to climb at the start of a turn, and in order to counteract that it was necessary to use a lot of rudder. It was considered that the extra surface and drag involved would not be compensated by not doing a slight climb. Hence it was we decided not to resist too strongly the tendency of the machine to climb when turning. On the other hand, there was a difference of opinion and at least one of us considered that the drag set up owing to letting the machine yaw upwards slightly, coupled with loss on the turn was greater than extra rudder used on a level turn. Now we came to the more difficult question as to whether the turn should be tight or loose. In other words, small or large diameter. In a fairly low-speed aeroplane, an efficient tight turn is done with the stick right back at, say, 3 *g*. At 300 m.p.h. the most efficient turn lay somewhere between 4 and 6 *g*. If one did a tight turn one lost more speed and travelled a shorter distance and *vice versa*. The question was to decide which was the efficient one. For this purpose we had Hardy and Wright attached to us from R.A.E., and they inserted in our training machines various complicated working instruments which they told us kept an automatic record of accelerations, speeds, and climb. By doing out turns over a carefully measured strip on the coast, they were able to find out

(1) The diameter;
(2) *g* at any point;
(3) Time taken and speed of machine.

From this data our X chasers evolved the perfect turn.

I showed you just now how very easy it was to put a big *g* on oneself and the machine. If about 5 or 6 *g* are put in on a sustained turn, there is quite a possibility of the pilot seeing "black." This is explained by the medical people as being due to the blood being drawn from behind the eyes back to the heart owing to centrifugal force. The effect starts with a slight dimming, and if the force is sustained you lose your sight. It is as if a black film comes

over your eyes. The effect lasts only so long as the centrifugal force is maintained. The pilot does not lose consciousness, but it seemed to me that one lost one's quickness of thought, and that if done repeatedly, had a decidedly weakening effect. The way to get the greatest g is by pulling the machine out of a dive and although it is easier to obtain higher g in this way, the pilot can withstand such a sudden application more easily than a sustained g in a turn.

Different pilots can withstand different amounts of g varying as to their physical fitness and the way they are built. Most of us seemed to go black between 6 and 7 g in a sustained turn.

With regard to training, we knocked off alcohol, and as two of us were teetotal, and three *not* very keen on drink, this wasn't very difficult. Three were already non-smokers and the other two cut their cigarettes down to a minimum. We took our training fairly free and easy as the medical view was that it was difficult to lay down any hard and fast rules as the Service had done so little high-speed flying. But if we kept fit we shouldn't go far wrong. We played tennis and did a lot of swimming, but had no special diet or special physical exercises. Before leaving our training period I should like to mention the question of maintenance. All our machines which we had for training were designed to stand up to about one hour's full-throttle flying. With this end in view, cowlings, fairings and radiators were not built with quite the solidity that one associates with the Service machine; weight had to be kept to a minimum. In the same way the plugs in the high-compression engine would only stand up to three practice flights. Hence it was that we were hard put to it to keep them serviceable. They were being put to a longer life than was at first intended and as a consequence we had to contend with leaking radiators, split cowlings, and a very frequent change of engine. It necessitated a lot of overtime and night work and we were very grateful to the way our mechanics got down to it.

The New Machines

The first of our new machines arrived on August Bank Holiday. It was an S.6.—No. N.247. You may wonder why we received it at such a short time before the race. The reason is that the machine is started and built to the specification of the engine. While the machine is being built the engine is being tested, developed, re-tested and re-developed, and so on. In the process, the engine shape, power, consumption and cowling are altered and all the time the machine must follow the engine. Attempts are being made to increase the power as increased power means increased speed. The time comes when someone must call a halt and decide to sink or swim with the power we have.

And hence it was that owing to the importance of added power they kept on developing the engine until the last possible moment and we only got the delivery at rather a late date.

With the arrival of the S.6 our hopes had risen considerably only to be immediately lowered to the depths when Squadron Leader Orlebar started his initial tests in Southampton Water. The S.5 in her take-off had been so straightforward that we had assumed that her elder brother would also prove himself equally docile while being broken in. We were therefore very surprised to see the behaviour of the S.6 on her first test. The S.6 behaved much as a horse refusing a fence. She sat on her tail and it seemed as if no amount of coaxing would get her forward. Furthermore, she dug her left wing into the water and not content with so much mischief started a gigantic porpoising. Time and again the Squadron Leader tried, and although he had overcome the porpoising, she still continued to dig her left wing in and to swing viciously to the left. To the rest of us in the Seacar alongside it was a heart-rending although impressive sight. From the Seacar we had a close-up of the whole proceedings,

and a very good view it was, not that one could see much of the pilot and fuselage, as most of the time they were enclosed in a whirl of spray. After about half an hour of this we returned to Calshot in a rather dejected frame of mind, as it certainly had not been a good beginning. The main trouble was the wing digging business and due, without doubt, to the enormous torque effect of the slow revving engine and propeller. Mitchell's first move was, therefore, to shift nearly all the petrol into the starboard float and to put in hand the immediate construction of a new and larger petrol tank for this float. The result of this was in the end satisfactory though there were a good many anxious trials before she got safely into the air. To start with it was a peculiarly delicate task for Squadron Leader Orlebar. He was swinging, he knew, and his left wing wasn't very far from the water and still he couldn't tell how much owing to the mass of spray enveloping the fuselage. He found out subsequently that a lot of the initial resistance to any acceleration was in part due to the very smooth, almost oily state of the water on which the first taxying trials took place. The surface of the water as viewed from the possibilities of high-speed flying is "glassy," which is, of course, dangerous, because the pilot cannot judge his height for landing even if the floats would leave the water, which is doubtful; "oily," "slight chop" and "slight swell;" the latter prohibits high-speed flying in that it tends to throw the machine off badly in the take-off before flying speed has been reached; it also strains the machine.

The difference in behaviour in the S.6 when she passed from an oily to a rippled patch was most interesting. If an oily sea she careers in a vicious circle like a kitten chasing its tail, but as soon as she got on to the faintest ripple she could be got on to her step and made to accelerate. I was once watching Atcherley trying to take her off. The sea was oily and the machine obstinate. She never looked like even getting on the step. Atcherley shouted to me that he was packing up. We had, however, noticed a patch of rippled water in the distance, and got him to try once more over on that particular bit. The result was magical, and he got off on the first attempt. The torque effect is greatest at slow revs. and the trouble was that being at the peak of the power drag curve, the drag of the floats was just about counter-balancing the thrust. The nose of the machine coming out very high and tail of the floats digging right into the water, set up a very high resistance. We had, therefore, to fit a faster revving propeller, with more power for the take-off. This also gave more power for the top speed; but we already had more power than specification and therefore more heat to dissipate than the original radiators were designed for. Hence it was going to be necessary to throttle down to keep the water cool. That very slight increase in wind, by about 4 m.p.h., made the difference; whether it was chiefly the increased control given to the rudder or chiefly the surface of the water affecting the floats, I am not prepared to say—perhaps a combination of both. But certain it was that provided you kept the machine into, or slightly to the right of the wind, you could get her on to the step. If she once got to the left of the wind it was hopeless. (I will describe her take-off with full load more fully later on). Whilst discussing these difficulties it is perhaps easy to assume that the S.6 had a bad take-off. Actually, this was not the case, provided one got her into the wind and on her step she accelerated like the proverbial gun. The S.6 appeared to stall about 3 m.p.h. slower than the S.5, but air speed indicators are not infallible at such a speed. However, it can be taken that she stalled in the region of 95 and was certainly no faster than the S.5. She was also extraordinarily stable at the stall. The S.5 would quiver at the stall and flick over either side at the slightest provocation. The S.6 showed no tendency to drop either wing, but would sink on an even keel. On one such occasion, while testing the stalling speed, I found the machine on an even keel sinking at about 87 m.p.h. When one considers the behaviour of her elder

brother at a similar speed it is all the more interesting, especially when you realise the extra top speed of the S.6.

While flying, she gave me the feeling of great stability, and when not flying low, the slow revs. of the engine gave me the impression that I remember I got when I flew a Horsley after having just left the seat of a Gamecock.

On turns she was delightful. Perhaps she was a little heavier laterally than the S.5 and the Glosters, but then she was a much bigger and heavier machine. There was no noticeable torque effect against a left hand turn which had been so tiring in the S.5, and, generally speaking, gave me a feeling of great trust and confidence, and I never had cause to change my opinion.

The Glosters arrived a few days after the first S.6, but unlike the latter, which arrived by sea, already erected, they had to be assembled, and it was not for many days that the first one was ready for the air. Misfortune dogged the Gloster VI. from its first flight, when Squadron Leader Orlebar had to execute a forced landing when she had barely risen 20 feet. The landing was perfect, but it showed that the minimum area for high-speed flying should be three miles long. The Gloster had been forced to land owing to some petrol installation trouble; bad weather had put off this last flight for a bit, so that when she was tested again, and it appeared to be cutting out badly in turns, Glosters found themselves with only a few days to go and a tricky little problem before them. They had also to put on more oil coolers, and it was time to put in the racing engine. Full praise must be given to the mechanics and staff of the Gloster Co., who, as one paper had it, "worked till they dropped" to get their machine in for the race. Right up to the last minute was the work carried on and the machine was tested as late as Friday morning. The same trouble again. We were all desperately sorry that the Gloster VI. couldn't fly in the race. It was our one great disappointment.

However, things were beginning to hum. The Italian team started to arrive shortly after the S.6 had done her trials. They brought with them a varied collection of seaplanes, including Bernhardi's old "Record" Macchi, which had been converted into a training machine by giving her more wing surface, the M.67, which they raced, and the twin-engined Savoia. They also brought a small Fiat seaplane whose supreme finish excited everyone's admiration. It was on this machine that only recently Dal Molin lost his life. The Italians, too, found they were even more pressed for time.

In order to simplify starting and to avoid taxying long distances and oiling plugs up, all the machines were mounted on pontoons.

We now come to the Navigability Trials, and the chief thing about September 6th was that it was my birthday, and although, of course, one felt that it should have been September 7th, one couldn't help feeling that it was an obviously most patent omen and that coupled with the cats, mice, elephants, and other harbingers of luck that one received, ought to do *some* good.

The other thing that concerned me on September 6th was the extraordinarily perfect weather. Surely it could not be repeated two days running! However, miracles do happen occasionally. About the trials themselves there is very little to say. All machines did their three landings and take-offs successfully and taxied the required distance. They were then moored up to buoys off Calshot for six hours. All machines passed this test successfully, and it was with considerable relief when our machines were pounced on by their mechanics and rushed off to the hangars to be tied up for the morrow.

It was with rather mixed feelings that I took my first look at the sea on the morning of the race. After a period of training, made up of a series of disappointments, I fully expected that the weather king had some card up his sleeve which he would produce on that memorable day. It did not require much to cause a postponement, which would be a source of disappointment to thousands of people.

The slightest swell or white horse on the one hand, and a dead calm on the other, were the limits that bounded our capabilities.

The day was unique, a deep blue sky of a type rarely seen in this country coupled with an amazingly good visibility. At the time it was blowing 10 miles an hour, and all was bustle on the tarmac. Some machines were already on the pontoons, while others were black with mechanics, using the last minute for finishing touches. The machine that I was to fly—N.247—was not yet out. Only eight hours before, one of the Rolls Royce mechanics noticed a small bit of metal on the electrode of one of the plugs; uneasy, they removed the block to find a seized piston and hopelessly scored cylinder. What bad luck! No one considered it possible to be able to change the cylinder block of this particular engine in the time left. Under ordinary conditions, Rolls wouldn't undertake it while in the machine, and it was midnight before the race! The story of how that block was changed, how their specialists, by chance in Southampton, were waked by police, is well known. Suffice it to say that these mechanics did it, and by so doing saved the Trophy.

It was about 10.30 on Saturday morning when 247 came out of the hangar and had her final run-up. Soon after this she was put on her pontoon and joined the queue of shipping which was still emerging in one long stream from Hamble river and Southampton Water. She had about two miles to go to the place that had been decided on for our take-off point. This was between Lee-on-Solent and Calshot, and was so chosen because of the wind, which was S.E. Here were already anchored the big pontoon with the three Macchi's and our other pontoons with Greig's and Atcherley's machines on board. There was also the official starting ship—the "Medea."

At about seven minutes to two my engine was started by Lovesay, the Rolls expert, and was run by him for barely two minutes. I then climbed in and made myself as comfortable as possible. At two minutes to two I was lowered into the water and started to take-off immediately. I will here digress slightly and describe in detail the procedure followed after opening up the throttle, as the S.6 was in many ways peculiar. Owing to the slow revs. of engine and propeller, coupled with the great power and consequent torque effect, the first thing that happened on opening up the engine was that the left wing tried to dig itself into the water. This almost submerged the left float, and the drag so produced swung the machine rapidly to the left, making her quite uncontrollable; the more the machine swung to the left of the wind the more rapid did the swing become until centrifugal force became greater than the drag of the left float, and she would suddenly throw her right wing down rather violently making it essential to shut off the engine. With a fairly fresh wind and full load it is advisable to take-off directly into wind, and with that end in view we found it essential to point the machine about 70 degrees to the right of wind and to have right rudder on from the start. The machine then runs along with its left wing a few inches from the water across wind, but not swinging. She is clear of the spray, which up to 30 m.p.h. completely envelops the pilot. Having got her therefore running across wind at 40-50 m.p.h., one is now confronted with what is really the trickiest part of the proceedings, and that is to get her into the wind without letting her swing right round, which she will want to do; once left rudder is applied the machine will accelerate rapidly, provided you have not put on too much rudder should reach her hump speed by the time she is directly into the wind. At this point she assumes a new position on the water—very much lower in front—and accelerates rapidly up to taking-off speed. She seems to leave the water at about 100 miles an hour, and I have never been able to take-off with full load without two or three bounces.

To return to the race, once off the water I made my way towards Old Castle Point, and then turned left and dived down over the starting line at about

350 miles an hour. The pylons were mounted on destroyers and stood out quite well, provided they were not anchored against a background of shipping. One could not get a view directly ahead and I had to pick up the correct line largely while turning the previous pylon. On the long legs we picked our course mainly by landmarks or shipping which we passed over. As an example, the Seaview turn was anchored, say, half a mile from the shore. By plotting our radius of turn on the chart and from previous practice, we knew that we should have to have the coast, say, five hundred yards on our right. By aiming to do this we would arrive in approximately the correct position; when within about 200 yards off the pylon we could see it, so that the actual turn itself was gauged with the pylon in view.

The first lap was naturally the most difficult, because we were not used to the various groups of shipping, which afterwards helped so much to our course keeping. As an example, while passing the Seaview turn on my first lap, I looked for the Chichester turn ship and picked out the only isolated vessel in that area. I made for it, and while still some little way from it, saw the pylon away on my left. I had been quite unable to see it as it had had a background of shipping immediately behind it. The ship which I had mistaken for the turn ship was, in fact, an oil tanker, and should not have been allowed to stray where it had. Atcherley actually turned round it. My own detour cost me six miles an hour, and that is the reason my first lap speed was only 324. From the Chichester turn I could see the Southsea pylon while still turning and had no difficulty at all in passing it, the esplanade on my right being also a great help. Next I came to what was the most difficult leg of the course—that from Southsea to Cowes—as there was no land and practically no shipping to guide one on approaching the turn. To make matters more interesting for the competitors, someone had conveniently parked a Flotilla of Destroyers immediately behind the pylons; hence the amazing turns of some of the Italians embracing all the Destroyers. I think in any future race (if there is one) the authorities should make quite sure that there be a lane quite clear of ships behind the pylon as viewed from the direction of approaching aircraft; this, of course, isn't the same thing as a lane in continuation of the actual course, since the aircraft approach the turn very wide. Once round the Cowes turn the course was plain sailing again, there being plenty of shipping and the shore of the Isle of Wight to help one.

I had completed several laps, everything was going beautifully—never a miss from the engine, and the machine handling perfectly—when I noticed the Italian Macchi diving towards the starting line just as I was coming up to the Cowes turn; at the Seaview turn I couldn't see him at all; at the Chichester turn I saw him a speck in front, and at the Southsea turn I saw him disappearing over Alverstoke. This time much nearer, and I was obviously overtaking him rapidly, the question was—could I overtake him on the straight before the Cowes turn, or just after? I hoped for the latter, for if I should catch him before the turn I should not be able to see him. However, it planned out as I hoped, for on rounding the Cowes pylon I saw him just coming out of his turn a few hundred yards in front. I decided to pass him on the inside and swung about a hundred yards to the left to clear him. I passed him about half way down the straight.

By now I had completed five laps and everything was going just as it should. The air in the cockpit was very hot, but owing to a stream of fresh air from a ventilating pipe over my face I wasn't too uncomfortable. An attempt to rest my knees on the sides of the fuselage was abruptly stopped when I discovered that they were, to all intents and purposes, "red-hot," a slight exaggeration, perhaps, but that is what it felt like, and through my slacks, too! I was flying at about 150 to 200 feet, as I found at that height I got

the best view of the course, and it was sufficiently low to be able to keep level. I had been running all the time somewhat below full throttle, as owing to the unexpected increase in power and consequent petrol consumption of the engine, she would not last the course with the petrol we were able to safely carry. The rate that petrol can be poured out of a two-gallon tin will give some idea of the rate that the engine was consuming its petrol during the race. I had therefore been told on no account to use full throttle as I shouldn't finish the course; imagine, then, my feelings when the engine momentarily cut right out and started missing badly just after I had finished what I imagined was my sixth lap. Would the Rolls engineers ever believe that I hadn't given full throttle? I began to gain height and continued round the course with the engine spluttering and only taking about half throttle. I climbed as much as possible in the hope that should she run right out, I could perhaps glide the remaining distance over the line. I was incidentally getting a very fine "bird's-eye view" of the entire course, but under the circumstances was not impressed. I got to the Cowes turn, and while banking, the engine cut out completely, and I was forced to land off Old Castle Point—only a few miles short of the finish. I leave my feelings to your imagination.

It was twenty minutes later that I learnt I had done an extra lap, and I also realised how deadly accurate had been Lovesay's estimation of the petrol consumption.

When one read the accounts of the race afterwards, one got rather the impression that it was little short of a miracle that the engine didn't blow up, such was the great effort it was making. I should therefore like to emphasise that such was the monotonous regularity of the engine (I don't suppose she varied by 15 r.p.m. throughout the race), and such was the stability and controllability of the machine, that I could easily have completed another five laps; hence, you can easily understand my great admiration for Mr. Royce and Mr. Mitchell.

Before ending, I want to stress what an enormous team effort the whole thing was. Nothing could have been less individual, for only a super-combined team, composed of literally hundreds of people, made the thing possible.

Discussion

Mr. Bruce: Was the water in the radiator anywhere near the boiling point during the race, and was any trouble experienced on this account?

Flt. Lt. Waghorn: This was the case, and it was partly on account of this difficulty of cooling off the increased power that the engine was giving, that the machine was flown somewhat below full throttle during the race, and the speed was maintained at a very steady rate—there being only about 15 r.p.m. variation in the engine all the time.

Mr. P. W. Petter: Was any difficulty experienced from eyesight strain when turning?

Flt. Lt. Waghorn: It was easy to "go black" due to action of centrifugal force causing the blood to recede from the back of the eyeballs, but this effect was always controllable by reducing the amount of g, and he personally took care not to "go black" on the turns during the race. It was very easy to avoid this and it was entirely in the pilot's hands as to whether this occurred.

Capt. Palmer: Had participation of more machines at the same time in the air as aiding the spectacular standpoint been considered?

Flt. Lt. Waghorn: It had been considered, and in his opinion there would be a certain amount of risk in permitting more machines up at the same time, as it was very difficult to see a machine in front if straight ahead, the range of sight being strictly limited by the position in the machine.

A Member: What was the maximum dive permitted to competitors on entering the speed course at the starting point?

Flt. Lt. WAGHORN: He was not quite sure of the exact amount, but thought it was in the neighbourhood of 1,500 feet. He considered that this dive should not be allowed.

Mr. GAUNT: He presumed there was a fair amount of error in the air-speed indicator reading which called for correction, and he enquired as to the actual position of the " pitot " tube.

Flt. Lt. WAGHORN: The amount of error was approximately 12 miles per hour. The " pitot " tube was placed about two feet inwards from the wing tip and standing forward about eighteen inches from the leading edge.

A MEMBER: Did the lecturer consider that the Italians lost any time by their method of climb adopted at the turns?

Flt. Lt. WAGHORN: It was left more or less to the individual judgment of the pilot how to turn. There was always a slight tendency of the machine to climb due to aileron drag, and they allowed the machine to follow its natural inclination to a certain extent; such was the force on the rudder to keep the machine level in a turn that it was thought that the extra inclined surface of the rudder would set up too much drag. He did not think the Italians were used to their new machines and probably would have not climbed so much if they had had more practice.

A MEMBER: There was some disappointment in the result of the straight flight speed after the race only reaching 357 miles per hour instead of the 370 anticipated, and asked whether there was any cause for this.

Flt. Lt. WAGHORN: The result obtained was certainly less than was expected, possibly due to the propeller being changed—the new one apparently being unsuitable—and many have even acted as a brake in the dive.

A MEMBER: How much petrol was carried by the lecturer's machine?

Flt. Lt. WAGHORN: There was a supply estimated as sufficient for 50 minutes, and the rate of consumption was nearly 2½ gallons per minute.

A MEMBER: Would the contemplated deletion of the tests for seaworthiness materially affect machines to be used in future races?

Flt. Lt. WAGHORN: He did not think so, because machines must be built sufficiently strong and seaworthy to withstand the normal stresses encountered in the take-off and landing conditions.

A vote of thanks to the lecturer was passed and the meeting closed.

AERODYNAMIC THEORY

BY

H. GLAUERT

(*Lecture read before the Hull and Leeds Branch on March 7th, 1930.*)

To attempt to discuss aerodynamic theory in a single lecture is perhaps a rather rash undertaking, for the subject is so vast that a proper discussion would require a volume, or even a series of volumes. My object, however, is not to cover the whole field of aerodynamic theory with its manifold applications to aeronautical engineering, but rather to discuss some of the fundamental conceptions on which the theory rests, and to discover where theory can be helpful and where it is necessary to rely wholly on experimental results. Hydrodynamics is the branch of mathematics which deals with fluid motion, and the equations of motion of a fluid, representing quite correctly its physical properties (density, viscosity and compressibility) have been known for many years. Unfortunately these equations are very complex and, except in a few special cases, it has been impossible to obtain solutions without passing to the simplifying assumption of a non-viscous incompressible fluid; and when the motion proceeds in such a perfect fluid, the theory leads to the astonishing conclusion that a body experiences no force owing to its motion through the fluid. Classical hydrodynamics therefore fell into disrepute except as a mathematical exercise for those who were sufficiently foolish to devote their time to it. In the last twenty or thirty years, however, some modifications have been introduced into the classical theory, and with these modifications modern hydrodynamic or aerodynamic theory has become a valuable tool for the development of aeronautics.

To understand these modern developments it is necessary to consider the effects produced by the viscosity and compressibility, which are assumed to be zero in the perfect fluid. The compressibility of the air needs no description. It is one of the fundamental properties of a gas, but in general the compressibility of the air exerts less influence on aerodynamic phenomena than the other less obvious physical property of viscosity or internal friction. One result of the compressibility of the air is of course that the density decreases with the pressure in rising upwards through the air, and this is accompanied by the well-known effects on the performance of an aeroplane, but at any one height the air can be treated as virtually incompressible. The unimportance of the compressibility of the air is due to the very small changes of pressure caused by the passage of an aeroplane. Consider, for example, the pressure in a pitot tube ($\frac{1}{2}\rho V^2$); even at a speed of 150 m.p.h. the pitot pressure is only 0.4 lb. per sq. in., *i.e.*, $2\frac{1}{2}$ per cent. of the atmospheric pressure, and thus the corresponding variation of density is negligibly small.

As the measure of the compressibility of a gas it is convenient to use the velocity of sound, which is transmitted through the gas by a succession of pressure waves. In air under standard conditions the velocity of sound is 1,120 f.p.s., or 765 m.p.h., and this velocity varies as the square root of the absolute temperature. Thus, at 20,000 ft., where the temperature has fallen from 15°C. to −25°C., the velocity of sound is 1,040 f.p.s. In general, the effects of the compressibility of the air do not become noticeable until the velocity rises to a value comparable with the velocity of sound. This point can be illustrated by referring again to the ordinary pitot tube used in measuring the speed of an aeroplane. The speed is deduced from the pitot pressure on the assumption that this pressure is $\frac{1}{2}\rho V^2$, but when the velocity is high the pitot pressure

is increased above this value by the compressibility of the air. Approximately, the pitot pressure becomes

$$\tfrac{1}{2}\rho V^2 (1 + V^2/a^2)$$

where a is velocity of sound. If this increase is ignored, the speed deduced from the pitot pressure will be too high, and numerical values of the true speed V and the over-estimated speed V' are as follow:—

V/a ... =	0.2	0.4	1.0
V (m.p.h.) =	153	306	765
V'/V ... =	1.005	1.02	1.13

At 150 m.p.h. the error is only ½ per cent., but at 300 m.p.h. the error has risen to 2 per cent., or 6 m.p.h., and so this effect is quite noticeable in a racing aeroplane.

The effect of the compressibility of the air may also become important with high speed airscrews, whose tip speed frequently approaches or even exceeds the velocity of sound. Theory has been of little assistance in elucidating the forces experienced by the blade elements at these very high speeds, but an approximate calculation of the effects of compressibility has suggested that the first result of the increasing speed will be to intensify the forces on the blade elements. This rough theoretical analysis suggests that the lift coefficient of an aerofoil section at a definite angle of incidence will be proportional to $(1 - V^2/a^2)^{-\frac{1}{2}}$, and the numerical values of this factor are as follows:—

V/a ...	0.2	0.4	0.6	0.8
Factor ...	1.02	1.09	1.25	1.67

Thus, at a speed of 0.6a, or 670 f.p.s., the lift coefficient of an aerofoil will be increased by 25 per cent. This increase is confirmed by results which have been derived by analysing the thrust distribution along the blades of some high speed model airscrews and, as might be expected, the drag increases with the lift. The experiments showed, however, that this theoretical law was obeyed only for a limited range of speeds, the exact upper limit depending on the shape of aerofoil section, but lying generally somewhere between 0.6 and 0.7 of the velocity of sound. Beyond this point the flow appears to break down in what may be called a " compressibility stall," which seems to depend on the fact that the velocity on some part of the surface has reached or exceeded the velocity of sound. At these higher speeds the lift begins to fall off and the drag to increase rapidly. These efforts depend, of course, on the shape of the aerofoil section; airscrew sections of conventional shape are worse than sections of the Joukowski type, and thick sections are worse than thin sections. These conclusions, derived from tests of model airscrews, have been confirmed by flight tests, while full-scale tests in the American propeller research tunnel have shown that there is very little compressibility effect on airscrews with thin blades.

Summarising these conclusions, we may say that the compressibility of the air is unimportant generally. There is a small correction to the speed read by a pressure head of a racing aeroplane, and there is an influence on the performance of high tip speed airscrews with blades of the usual thickness. This effect is at first an intensification of the forces, implying an increase of the thrust and torque without any change of efficiency, but at still higher speeds the thrust and efficiency will begin to fall. Unless allowance is made for these effects of compressibility in the design of the airscrew, the airscrew will fail to develop the full engine revolutions owing to the increased torque.

Turning next to the viscosity or internal friction of the air, it is convenient to separate its influence on aerodynamic phenomena into two parts—the direct effects which are represented mainly by the frictional drag of any moving body and the indirect effects which modify the whole type of flow past the body. The viscosity of a fluid or gas is defined by a coefficient μ, so chosen that the shear

force between adjacent layers of fluid flowing in the same direction is μ times the velocity gradient, or

$$F = \mu \, (du/dy)$$

It is more usual, however, to use the kinematic coefficient of viscosity ν, which is this coefficient μ divided by the density ρ. Now the force on a body can be expressed in the form

$$F = kS\rho V^2$$

where S is some suitable area and k is a non-dimensional coefficient. The value of k depends on the shape and attitude of the body mainly, but it also depends on the Reynolds' number of the flow

$$R = lV/\nu$$

where l is some typical length of the body and R is a non-dimensional parameter. Two bodies of the same shape, but of different size, will have the same type of flow and give the same lift and drag coefficients only if the speed or viscosity are adjusted to maintain the same value of the Reynolds' number R. This is one of the difficulties of model experiments in a wind tunnel. The viscosity is the same as in the corresponding full-scale flying test, the speed V is approximately the same while the length l is much smaller. Thus we cannot hope to obtain the same conditions of flow, but fortunately in many problems the difference is negligibly small. Scale effect, however, is always possible and cannot be neglected until suitable tests have shown that it is unimportant, or unless we can produce some theoretical arguments to suggest that it will be unimportant.

To understand the effect of the Reynolds' number it is best to start with the flow in a long straight pipe of circular section. At very low speed or at low Reynolds' number the flow is laminar, *i.e.*, the fluid all moves steadily parallel to the axis of the pipe, and in this condition the velocity distribution across any section and the frictional drag on the walls can be calculated. Experiments also are in exact agreement with these calculations. As the speed or Reynolds' number increases this laminar motion becomes unstable, the flow breaks up into a succession of eddies and as yet theory has been unable to give any satisfactory account of the motion of the fluid.

The conditions for the flow along a flat plate are very similar to those in a pipe. At low speeds there is a laminar flow, for which the frictional drag has been calculated in agreement with experimental determinations, but at higher speeds the flow becomes turbulent and the frictional drag is increased. In practice, too, the conditions are even more complicated, since a laminar region occurs along the front of the plate and is followed by a turbulent region farther back. The curve of drag coefficient therefore follows the laminar curve to a certain joint and then passes along a transition curve to the turbulent curve. This behaviour, which is confirmed experimentally, introduces complexity into the interpretation of wind tunnel tests of the drag of struts or symmetrical aerofoils, since the observations are made either before the transition stage is reached, or during the transition. The point at which the transition commences may depend on the roughness of the model and on the turbulence which exists in the flow in the wind tunnel and thus comparative tests, particularly in different wind tunnels, may be of little value. When the final full-scale conditions are attained, the frictional drag probably approximates closely to the turbulent drag of a flat plate, and this conclusion appears to be valid not only for aerofoil sections but also for bodies of revolutions such as airships. This does not imply that all aerofoil sections ultimately have the same drag, since the frictional drag is only one part and the pressure distribution round the section gives a further contribution to the drag. From this discussion it appears that the direct effect of the viscosity of the air is to cause a frictional drag, and that this drag depends on the Reynolds' number of the motion. Fortunately, however, this frictional

drag is generally only a small part of the force experienced by a body, and so a little uncertainty in its value is not of too great importance.

Passing now to the indirect effects of viscosity, consider the flow past a circular cylinder. In a perfect fluid the streamlines would divide as they approached the cylinder, pass round its sides, and rejoin again at the back. The flow is symmetrical fore and aft, and there is no drag force. In a real fluid the flow is very different. As the air passes along the surface of the cylinder it is retarded by the frictional drag and loses some part of its original energy, and this process goes on until the air no longer has sufficient energy to advance against the increasing pressure which occurs along the back of the cylinder in the symmetrical flow. Thus the air is forced from the surface, there is a reverse flow on the back of the cylinder, and the final condition is that the streamlines break away from the shoulders and leave a stagnant wake behind the cylinders. Also these surfaces of discontinuity are unstable and break up into a succession of eddies which ultimately arrange themselves in a regular pattern. This type of flow was studied by Karman and is called a Karman vortex street. The drag of the cylinder can be calculated from the width of this vortex street and from the strength of the eddies, and this calculation is based on the assumption of a perfect fluid. The frictional drag on the surface is a very small fraction of the total drag, and thus the flow past a circular cylinder is an example of the indirect action of the viscosity. It is necessary to introduce the viscosity to explain the type of flow which actually occurs, but granted this type of flow, the drag can be calculated without any reference to the viscosity. The actual strength of the viscosity is unimportant; so long as there is any viscosity the vortex street will develop, and the resulting drag is independent of the strength of the viscosity. In fact the viscosity is simply a demon who has pulled the trigger and changed the ideal flow of zero drag into the actual flow with its large drag.

The demon of viscosity acts by making the flow break away from the surface of the body, and the lesson to learn is that precautions must be taken to prevent or delay this break away. Bad features in this respect are any irregularities or projecting fittings on the surface, since these disturb the flow in the viscous boundary layer and tend to cause the flow to break away, and even an abrupt change in the radius of curvature of the surface may act in this way. As remedial measures, which tend to hold the flow on to the surface, there are the Handley Page slot for aerofoils and the Townend Ring for bodies. Both these devices seem to act in a similar manner by supplying fresh energy to the viscous boundary layer, and thus they delay the break away of the stream from the surface. An alternative scheme, which has as yet been tried only on models, is to suck the viscous boundary layer into the body at some suitable points, and by means of this suction the flow can be made to conform almost exactly to the theoretical flow in a perfect fluid. Whether this scheme can be employed in practice depends on the quantity of air to be dealt with and on the power required to suck it from the surface and to discharge it elsewhere. The experiments have hardly reached a stage where a definite answer can be given, but the efficacy of the scheme is quite certain.

The indirect action of the viscosity is also the clue to the behaviour of an aerofoil. Starting from the conceptions of classical hydrodynamics, the first problem is to explain how there can be any force on the aerofoil, and this problem was virtually solved by the work of Kutta and Joukowski, who showed that the aerofoil would experience a lift force if there was a circulation of the flow round its contour. This solution, however, immediately raised as a second problem the explanation of how this circulation could arise and of the strength of the circulation. Joukowski considered only aerofoils with sharp trailing edges and he assumed quite correctly that the strength of the circulation must be such

that the streams above and below the aerofoil united smoothly at the trailing edge. To understand the validity of this hypothesis it is again necessary to turn to the viscosity of the fluid. The perfect fluid solution will be satisfactory only if it is the limit of the viscous fluid solution as the viscosity tends to zero, and this implies that the viscous forces experienced by the fluid must be small compared with the inertia and pressure forces. If there is no circulation there will be a very high velocity round the sharp trailing edge of the aerofoil and, however small the viscosity may be, it will be possible to choose a point near this trailing edge where the viscous point is comparable with the dynamic force. If, however, the circulation is chosen so that the rear stagnation point moves to the trailing edge of the aerofoil, the velocity will be finite and this difficulty will no longer arise. Thus Joukowski's hypothesis for the strength of the circulation leads to a perfect fluid solution which is a possible limiting condition of a viscous fluid solution, and no other value of the circulation will satisfy this condition. The circulation is generated by the action of the viscosity which retards the flow round the trailing edge, and thus allows the flow on the upper surface to push the stagnation point backwards towards the trailing edge. More generally this discussion leads to the suggestions that perfect fluid solutions are valid only if the velocity never becomes very large, and that circulation of the flow and vorticity may be generated by the action of viscosity on any sharp edges of the body.

In the light of this discussion it is possible to gain some insight into the scale effect which may be anticipated on aerofoils. At moderate angles of incidence the lift will be sensibly independent of the viscosity and there will be no scale effect, but there may be a small effect on the frictional drag of the aerofoil. At large angles of incidence the flow breaks away from the upper surface of the aerofoil, the circulation can no longer be determined by Joukowski's hypothesis and there may be an important scale effect on the maximum lift of the aerofoil. Also at very small angles of incidence, where the lift is small and comparable with the frictional drag, scale effect may also be anticipated.

These calculations, based on Joukowski's hypothesis, refer essentially to two-dimensional motion or to aerofoils of infinite span, but Prandtl has shown how to derive the corresponding characteristics of aerofoil of finite span. This transformation is well known and I do not propose to discuss it now, except to remark that the induced drag experienced by an aerofoil for finite span is calculated for a perfect fluid and is not susceptible to any scale effect. By means of the theory so developed we can calculate the angle of no lift and the slope of the lift coefficient against angle of incidence, we can calculate the moment coefficient at zero lift and the slope of the moment coefficient against the lift coefficient, and we can calculate the induced drag; but we must rely on experiments to determine the maximum lift coefficient and the profile drag, and these quantities are both susceptible to scale effect. Calculations or experiments can be made for any shape of aerofoil, but there appears to be a real advantage in designing the aerofoil section by some theoretical process rather than relying on a draughtsman's art. Most of the aerofoil sections used in the past have been designed on the drawing board and the section R.A.F. 15 represents one of the best of these sections; but when a thicker section was desired the R.A.F. 30 series of sections was calculated by an extension of Joukowski's method and, at the very first attempt, a section was obtained twice as thick as R.A.F. 15, with the same drag and with a higher maximum lift. I do not believe that this result shows any special virtue in the particular transformation used in designing these thick aerofoil sections, but I ascribe it rather to using any mathematical formula. A draughtsman, designing an aerofoil section, will produce continuity of line and continuity of slope, but the mathematical formula will also give continuity of curvature. The draughtsman will not do this; indeed, his delight is to build

up a curve with a succession of circular arcs, and at each junction there is a sudden change of curvature on the surface which means a change of centrifugal force on the fluid, and requires an adjustment of pressure to maintain the flow. If the curvature changes suddenly, the fluid may not be able to adjust itself to the change and there will be a tendency for the flow to break away from the surface. In fact every sudden change of curvature is a potential disturbance of the flow and in aerodynamic design, whether of an aerofoil or of a body, all sudden changes of curvature should be avoided. Ideally, therefore, all curves used in aerodynamic design should avoid sudden changes of curvature; the simple method to achieve this result is to use a mathematical formula, and probably the simplest formula will give the best result.

Turning again to the aerofoil sections, it is interesting to note that any aerofoil section can be derived from a circle by means of a suitable conformal transformation. Such a transformation is often a complex mathematical process, but in principle it is merely a distortion of any picture according to the rules of map making, which requires that the shape of any small element shall remain unaltered by the transformation. In different parts of the map these elements may be magnified by different amounts and may be turned through different angles, but the shapes of all the elements remain unaltered. Joukowski's transformation is only one example of the transformation of a circle into an aerofoil, but it has the merit of being the simplest possible transformation. Simplicity is always desirable, and since the streamlines are distorted with the circle, the simplest transformation means the least disturbance of the flow. This is perhaps an argument in favour of the Joukowski aerofoils compared with more complex forms, which depend on more complex transformations.

Now a circular arc of camber γ set at zero angle of incidence gives a lift coefficient

$$k_L = 2\pi\gamma$$

and at this attitude the flow comes smoothly on to the leading edge and reunites smoothly at the trailing edge. If a symmetrical fairing is built round this circular arc, we obtain an aerofoil section whose minimum profile drag occurs at the lift coefficient $2\pi\gamma$ and is sensibly the same as that of the symmetrical section. A logical and satisfactory method of designing an aerofoil is therefore as follows:—Choose a good symmetrical section of the thickness required for the structure, and bend this section round a circular arc of camber γ, chosen according to the lift coefficient at which the best results are required. The only difficulty encountered is that the moment coefficient at zero lift, which is equal to $(\pi/2)\,\gamma$, may become too large; it is then necessary to add some reflex curvature to the centre line of the aerofoil section, thus reducing the movement of the centre of pressure at the cost of a small increase of drag and of a small decrease of maximum lift.

Finally, I should like to mention an interesting application of theory which has recently been tested in Germany. The induced drag of a wing of finite span is a minimum when the lift is distributed elliptically across the span, and fortunately our ordinary rectangular or tapered wings approximate closely to this condition. On the other hand, the wing is often broken at the centre by a small section of reduced chord, and the centre section causes an important increase of drag. There is an increase of profile drag because the aerofoil section is often of poor shape, but the more important increase is in the induced drag due to the drop of lift. Theory suggests that this increase of induced drag could be avoided if the lift were maintained at its proper value, and this can be done by using a more cambered aerofoil section set at a higher angle of incidence. It is necessary that the maximum lift coefficient of this section shall be higher than that of the main part of the wing, and if a high lift section is used it is necessary to use a slotted section at the centre. This idea, suggested by theory, has been tested experimentally with complete success, and shows once more the value of modern aerofoil theory.

HIGH ALTITUDE EQUIPMENT OF AIRCRAFT

BY

MAJOR STEWART

(*Lecture read before the Yeovil Branch, April 4th*, 1930.)

Notes on Heated Clothing

The problem of keeping pilots and observers warm when flying at high altitudes was brought into prominence during the late war. At a height of 20,000 feet the normal temperature is approximately $-25°C$. or " 45° of frost," whilst in winter at an altitude of 30,000 feet temperatures of the order of $-50°C$. or " 90° of frost " are frequently encountered. When flying at probably 100 miles per hour in temperatures of this order, all ordinary means of keeping the body warm are quite inadequate and no padding or lagging capable of being worn as a suit will keep the body warm for more than a few minutes.

The first attempt at heated clothing was made early in the war.

The method consists of incorporating resistance wire in the clothing, and heating this by passing an electric current through it.

The electrical energy is derived from a wind-driven generator mounted externally on the aircraft. The output from this generator is led to an automatic voltage control box in the cockpit and from there to a small switchboard and a multi-pin plug mounted in a convenient position on the cockpit wall.

The voltage control box is a magnetically operated device and automatically maintains a constant voltage independent of the speed of the generator and of the electrical load.

The clothing is divided into four main sections, *i.e.*, " Body," " Hands," " Feet," and " Goggles," the latter being a comparatively recent development. On the switchboard are four switches with the appropriate labels. The heat to the body, hands and feet is controlled by merely switching on or off, but the circuit to the goggles has a rheostat incorporated for a finer adjustment of the heat.

In the original form the heated clothing took the form of a sleeved waistcoat, gloves and soles to put inside the boots.

The articles were put on separately and interconnected by means of plugs and lengths of flex to a main plug on the side of the waistcoat, from there a length of flex connected to the multi-pin plug on the side of the cockpit.

In this early form the electrical energy was supplied at a pressure of 12 volts and the total power taken was about 70 watts, no heating being supplied to the goggles. The heating elements consisted of plain nichrome wire, but this was soon found to give trouble through breakages at various points due to constant flexing.

It was also found that the heating was not adequate and that the clothing was a nuisance to put on, as the ordinary coat and waistcoat had to be taken off first.

It was decided therefore to produce a combination suit consisting of a special flying suit heavily padded with " Capok " and having the heating elements sewn in behind the inner lining.

The first type produced was the Mark I., this consumed a power of 250 watts, the electrical pressure being raised to 14 volts.

Instead of the plain nichrome wire, stranded " Eureka " wire was used for the heating elements. The heating elements are confined to the back and

shoulder blades, the hands, both the palm and the back, and to the feet and ankles. It has not been found necessary to heat the front of the body or the arms or legs.

Particular attention is paid to the wiring for the fingers, the wire running up one side, over the finger tip and down the other side for each finger, a little extra heat is given to the thumb.

The Mark I. heated suit was a great improvement on the previous clothing, but various difficulties again presented themselves.

The legs of the suit were continued down and included a padded and heated foot; the foot was found to be too bulky, so much so, that in some cases the foot could not be inserted into the strap on the rudder bar. Also, the stranded " Eureka " wire, although an improvement, still gave trouble by breaking.

The suit was then modified by attaching the standard sheepskin flying boot from the knee downward and sewing the heating wires inside the boot.

Also stranded wire was abandoned and a new form tried consisting of a single " Eureka " wire wound spirally round an asbestos string core.

At this period the flexible metallic tubing supplying oxygen to the oxygen mask was also incorporated in the suit.

The electrical lead to the multi-pin plug leaves the suit on the left hip. The oxygen tube is incorporated in this lead, and on entering the suit, passes up between the linings and emerges near the left shoulder, going from there with a short lead to the oxygen mask. It was originally intended to incorporate the inlet to the oxygen tube in the same plug as the electrical leads, but owing to the possibility of fire due to an electric spark occurring in the presence of oxygen and ebonite, this was abandoned. The tube therefore branches from the lead a few inches from the end and is led away to a separate bayonet union.

This suit was found to be fairly satisfactory, but trouble was still experienced through breakage in the heating elements.

It was also found that although suitable for very high altitudes and low temperatures, there were many occasions when the heat was too great, and the trouble of constantly switching off when too warm, and on when too cold interfered with the duties of pilots and observers. To meet this requirement the Mark II. suit was developed, this was similar to the Mark I., but only consumed 120 watts at 14 volts, it had rather less padding than the Mark I. and had no provision for heated goggles or for oxygen.

At the same time, both the Mark I. and Mark II. suits were fitted with the latest type of heating element. This consists of 34 gauge steel wire wound in a fairly close spiral about 1/16 inch diameter. The wire is tightly wound on a mandrel, then taken off and pulled out longitudinally until the consecutive turns do not touch, it is then sewn into the suit without any further covering or central core.

This proved satisfactory, and in this form the suits are now issued to the service, the Mark I. being intended for really high altitude work and the Mark II. for medium temperatures and altitudes, at which oxygen is not required. The Mark II. is at present undergoing service type trials.

Heated Goggles

When flying under conditions of low temperature, trouble is experienced due to misting of the inner surface of the goggle glasses. The glass is cooled by the outer air to a temperature below the dew point of the air inside the goggle, and water vapour condenses out on the inner surface of the glass.

If the temperature is sufficiently low this water turns to ice and forms an opaque screen in front of the eye, which is almost impossible to wipe off under flying conditions.

The first attempts to overcome this difficulty were made about 1925, and took the form of a double glass, sealed round the edges, the space between the glasses being evacuated.

The evacuated space acted as a heat insulator and the outer glass was at air temperature, whilst the inner glass remained at the temperature of the air inside the goggle.

This attempt failed owing to the difficulty of finding a suitable sealing material, no material could be found which would withstand the large temperature variations and maintain the seal, whilst the cost of an all-glass unit was prohibitive.

Various other methods were tried and electrical heating was found to be the most satisfactory.

The electrically heated goggle consists of a fur-lined mask, having an elastic band to go round the head and metal frames inserted to take the glass eye-pieces.

Two glasses are used in each eye-piece, the glasses form a thin " sandwich " having between them a heating element consisting of thin michrome wire.

The wire is led to and fro across the whole area of the glass in vertical lines spaced about $\frac{5}{8}$ inch apart. The wires are so thin and so close to the eye that they are out of focus, and do not interfere with the vision.

The two eye-pieces are wired in series and terminate in two small terminals fixed on the top of the metal frames, from which a flexible connection passes to a plug and socket on the breast of the heated flying suit.

When placed direct on the heated suit circuit at 14 volts the goggles consume about 50 watts. Since this power is only required at very low temperatures, a rheostat is placed in circuit capable of reducing the power in the goggles to about 12 watts.

The rheostat is placed on the side of the cockpit where it can be easily operated, and an ammeter may be included in the circuit to give visual indication of the amount of current being taken.

When in use the rheostat is operated to maintain the goggles at a heat just sufficient to prevent any tendency to misting.

The existing design is satisfactory and is quite capable of preventing misting or freezing at any temperature likely to be encountered when flying.

Notes on Cockpit Heating

About 1921 it was considered necessary to isolate the pilot from the engine by means of a fireproof bulkhead, to prevent flames from a fire in the engine sweeping back into the cockpit directly on to the pilot.

This safety measure was carried out in nearly all aircraft.

Immediately this was done, however, pilots complained that they were deprived of the heat from the engine and felt much colder when flying; the need arose therefore of some method of heating the cockpit.

A preliminary experiment was carried out using a small radiator placed in the cockpit and heated by water circulating from the engine jackets. The experiment was not a great success and this method was abandoned on the grounds that it unduly complicated the water system and that it could not be applied to air-cooled engines.

The next experiments were made with an air heating system.

The system consists of placing a muff round the engine exhaust pipes; air is forced into the front end of these muffs by the forward motion of the machine, and is heated by passing over the hot exhaust pipe. The hot air is then introduced into the cockpit through apertures low down in either side of the fuselage, passes upwards through the cockpit and out at the open top.

The size of muff and the area exposed exhaust pipe are adjusted to give the right amount of heat, whilst the cockpit temperature can be adjusted by

means of a butterfly valve which either deflects all or part of the hot air into the cockpit or allows it to pass out at the back of the muff. By this means air is always circulating through the muff whether the cockpit is being heated or not; if the muff were to be completely closed the exhaust pipe would become red hot and burn away.

From the first, these experiments were successful and the work of development continued on the lines of finding the most convenient positions and sizes for the muffs and piping.

Since for safety the exhaust pipes and muffs must be outside the fuselage, the size and positioning are important if the drag is not to be unduly increased.

It is also even more important that the exhaust pipe and its joints be absolutely free from leaks, as any leakage taking place inside the muffs immediately fills the cockpit with poisonous exhaust fumes.

The first serious experiments in cockpit heating were made at the R.A.E. on an S.E. 5A aircraft in 1925, and although the experiments were rather rough and the aircraft was unsuited for high altitude flying, the results obtained were sufficiently promising to justify further experiments on more modern aircraft.

A Siskin III. with a supercharged Jaguar engine was therefore equipped with an improved form of hot air muff and minor modifications were made in the fuselage to conserve heat. The muffs were partially recessed into the fuselage and heavily lagged with asbestos.

Inside the fuselage a light three bulkhead was fitted just behind the pilot's back to prevent the escape of warm air away down the fuselage to the tail of the machine.

The forward cowling and windscreen were modified to exclude draughts and the lacing on the side of the fuselage was sealed with doped fabric strips.

Thermometers were installed, on one of the wing struts to give the outer air temperature, and at points inside the cockpit to record the temperature distribution.

Flight tests were then commenced and extended over a period of two or three years, the apparatus being modified from time to time, and machine being flown by a number of experienced pilots.

The tests usually took the form of a climb to about 25,000 feet, then level flying at that altitude until the cockpit temperatures had become steady, then a glide down with the engine throttled back to see how the cockpit temperature fell with the engine shut off.

The various temperatures were recorded by the pilot every few minutes during the whole flight.

Many flights were made, but except for slight alterations to the amount of heating area and the diameter of the pipes, little improvement could be made on the original arrangement.

The results obtained were most satisfactory. During the winter the air temperature at 25,000 feet was found to be about $-42°C$. When flying in this temperature without heating, the cockpit temperatures were found to be $-19°C$. at the instrument board and $-27°C$. at the pilot's back. When the heating was in use, however, the cockpit temperatures were $+2°C$. at the instrument board and $-14°C$. at the pilot's back.

As a result of the experiments, it is now considered that this form of cockpit heating is practicable and desirable.

No further experiments are to be carried out, but manufacturers are being asked to incorporate this feature in all new high altitude aircraft.

For single-seater aircraft, cockpit heating will enable pilots to dispense with heated clothing and heated goggles, but it is unlikely that heated clothing will ever become obsolete.

In two-seater military aircraft the duties of the observer involve a good deal of moving about and standing up, with the upper half of the body exposed to

the air stream. Also the top of the cockpit must be left quite open for the gun ring and in bombing machines a door must be opened in the floor of the cockpit.

Under these conditions it is impossible to keep the cockpit warm and the observer is obliged to wear heated clothing.

Oxygen

When aircraft became available, capable of climbing to altitudes at which really low temperatures are experienced, trouble began to be experienced with the h.p. oxygen supply.

Machines left the ground with the oxygen apparatus in good order, but after flying for a short time in a low temperature, the oxygen supply would fail and the pilot would be forced down.

In a few cases the pilots fainted through lack of oxygen and the machine came down out of control; happily the pilots recovered consciousness at about 10,000ft. and regained control.

When these machines landed the oxygen apparatus was examined and found to be again in working order, nothing being present to account for the failure.

After a good deal of investigation the trouble was traced to the presence of a small amount of water vapour in the oxygen contained in the h.p. cylinders.

In any gas the amount of water vapour capable of being held in suspension is reduced as the temperature is lowered. Thus, if a gas containing even a small amount of water is cooled, a critical temperature is reached at which the gas becomes saturated, any further cooling resulting in small beads of moisture being deposited on the walls of the container. If the temperature is below the freezing point of water, these beads of moisture instantly condense and form ice. A typical example of this phenomenon is the formation of ice on the inside of window panes in frosty weather, the cold outer air cools the glass which in turn cools the warm air of the room immediately in contact, the saturation point is reached and moisture deposited on the glass turns to ice forming the familiar patterns on the window.

In the case of the h.p. oxygen supply the amount of water vapour present is very small, and even under the low temperature at altitude, the gas remains dry in the cylinder and pipe line. On reaching the h.p. regulator, however, the gas has to pass through a reducing valve which reduces the pressure from 1,000lbs. per square inch to a much lower pressure of the order of 30 or 40lbs. per square inch.

It is well known that when a gas is expanded there is a fall in temperature, this fall takes place at the small orifice in the end of the brass centre piece.

The flow through the orifice is regulated by an ebonite plunger which descends on to the orifice and except under very heavy deliveries this plunger is always partially closing the outlet. The result is that expansion does not take place actually through the orifice, but radially outward between the orifice lip and the face of the plunger.

The gas is already at a temperature of say $-30°$C. and on expansion the temperature is further reduced by some 40°C. causing the gas immediately after expansion to be at about $-70°$C.

Having passed the orifice this gas is quite safe, but it is still in contact with the outside of the brass centre piece and in a short time the centre piece is cooled below the saturation of the oncoming high pressure gas inside it. As soon as this happens moisture is deposited in the bore and in the orifice, this instantly freezes, the orifice becomes choked with ice and delivery ceases.

When the delivery is stopped the cooling, due to expansion, is stopped and the ice begins to warm up, at the same time the aircraft comes down to more normal temperatures thus accentuating the warming process, and before landing the ice has melted, delivery has commenced again, blowing the moisture away and nothing is left to account for the failure.

To overcome this difficulty it was decided to raise the temperature of the oxygen immediately before it entered the regulator so that on expansion the temperature would not fall below the critical point.

Accordingly an electrical heater was designed. This consists of a short length of copper tubing having suitable unions at either end and being wound round first with a mica strip, then a length of michrome wire, then more mica and finally a heavy lagging of asbestos string with an outer casing of aluminium. The two ends of the heating element are led to a two-pin plug on one end of the casing and a flexible lead connects to the heated clothing circuit.

The heater consumes about 18 watts and effectually prevents freezing in the regulator under the lowest temperature conditions, even when free water is deliberately introduced into the high-pressure gas cylinder.

It was felt, however, that this could not be accepted as a permanent solution to the problem, as although the electrical circuit is very reliable, failures can occur and whereas a failure of almost any other item on an aircraft, even failure of the structure itself, means at the worst a forced landing or a parachute descent, failure of the oxygen supply means failure of the pilot, the machine comes down out of control and the pilot cannot even make use of his parachute.

The question of supplying oxygen, which was absolutely free from water, was taken up, and by extra care in the procuring of the gas and care in drying out the cylinders before each filling, it was found possible to obtain cylinders which, for all practical purposes, were free from water.

Although a step in the right direction even this was felt to be not sufficient, as it meant relying on the workmanship at the filling station, and among thousands of cylinders filled it was inevitable that here and there a " wet " cylinder would get through.

Work was therefore commenced on the design of a reducing valve which would continue to function even though water and ice were present.

After one or two experiments it was decided to adopt the " inverted " orifice type of reducing valve.

The valve works on the usual principle of a high-pressure inlet which is partially or completely closed by an ebonite plunger operated by a spring-loaded diaphragm in the low-pressure chamber. The radical difference is that instead of the plunger operating on the low-pressure side of the orifice, the orifice is made slightly larger, a spindle runs from the centre of the diaphragm on the low-pressure side, through the orifice, and carries the plunger on the high-pressure side.

The face of the orifice on the high-pressure side is conical and the plunger takes the form of an ebonite ball seating in the cone.

The advantages are twofold; firstly, there is no narrow channel to choke up on the high pressure side before expansion; secondly, if by any chance ice commenced to form on the walls of the orifice, the small but constant movements of the spindle passing through the orifice, break up the ice and it is blown clear.

This reducing valve has been put through most vigorous tests at the R.A.E. and finally was run for three hours without a heater, at a temperature of $-40°C.$, the oxygen being bubbled through water before entering the valve.

Although subsequent examination whilst still cold revealed considerable quantities of ice inside the valve, there was no failure and the valve functioned normally throughout the tests.

Subsequent flight tests have confirmed the reliability of this valve and it is hoped to issue it to the service shortly.

Further recent modifications to the oxygen installation on aircraft have been the substitution of all-metal joints in place of rubber sleeves on the low-pressure side of the pipe lines; the fitting of a new and more reliable type of flexible tubing to the oxygen mask; a new and improved form of bayonet union having a " T " shaped handle, and the incorporation of a small shield, or de-

flector in front of the inlet to the mask, to prevent the aperture becoming blocked by moisture from the mouth.

Work is also being carried out on a new and more reliable type of high-pressure shut-off valve for the oxygen cylinders and a new form of oxygen flowmeter having an evenly graduated 300° scale for oxygen supply up to a height of 40,000 ft. is in the experimental stage. It is hoped to issue these accessories to the service at an early date.

Stiffening of Controls

In 1928 attention was directed to the fact that as a machine climbed and the temperature became lower, the controls to ailerons, rudder, etc., gradually stiffened, and in some cases jammed completely. So long as the altitude and low temperature were maintained this stiffness persisted, but on coming down to normal temperature again the controls became free.

The matter was referred to R.A.E. for investigation, but owing to the difficulty of reproducing flying conditions and the difficulty even in full-scale experiments of reproducing similar conditions three or four times, the problem has not yet been completely solved.

It appears likely that the trouble is due to three main causes:—

(*a*) The use of lubricants in the bearings of any levers, etc., which are used to transmit motion.

(*b*) The unequal contraction of the wire forming the controls and the frame of the aircraft.

(*c*) The deposition of moisture on bearings, levers, etc., with subsequent freezing.

(*a*) If lubricants are used, then a certain amount of stiffening is inevitable as the viscosity of a liquid increases with a decrease in temperature, and many oils have a freezing point above the temperatures encountered at altitude.

A lubricant consisting of:—

Oil Gum P.924	...	...	...	55 per cent.
Paraffin	...	...	...	40 per cent.
Graphite Powdered		...	...	5 per cent.

has given some very satisfactory results, but aircraft designers are now endeavouring to make bearings designed to work without any lubricant.

(*b*) The stiffness due to unequal contractions has been investigated mathematically, and it has been shown that the amount of stiffening due to this cause is almost negligible at the order of temperature encountered. (See Appendix I.).

(*c*) The deposition of moisture cannot be very well prevented, experiments are difficult to carry out and results uncertain, as the deposition depends on the humidity of the atmosphere, which may vary from hour to hour and may be different at different altitudes.

Designers are endeavouring to overcome this difficulty by reducing bearing areas to a minimum and fitting rocking devices instead of journal and spigot bearings.

Further laboratory and full-scale tests are still to be made.

APPENDIX I.

Note on the Possibility of Stiffening due to Shortening of Control Wires

The possibility of stiffening due to shortening of control wires may be explored by consideration of a typical case, say, an aileron control wire extending outwards along a wooden wing twenty-five feet.

Assuming the coefficient of linear thermal expansion for steel cable to be 11×10^{-6}, ditto for spruce 5×10^{-6}, a drop in temperature from $+20°C.$ to $-50°C.$ would result in a total contraction of

$$70 \times 6 \times 10^{-6} = 0.00042$$

(*i.e.*, 0.126 in. in 25 ft.).

Assuming an apparent modulus of elasticity for the cable to be 22×10^{6}, the increase in tension would be

$$0.00042 \times 22 \times 10^{6} = 9240 \text{ lb./sq. in.}$$
$$= 4.12 \text{ tons/sq. in.}$$

i.e., for a 20 cwt. cable of 0.013 sq. in. cross-sectional area, an increase in tension of 0.0535 tons or 120 lb.

This calculation does not take into account movement of pulley mountings, etc., which would reduce the above figure. In any case, as the pulleys are mounted on ball bearings and as fairleads are used only for small angular deflection of cables, the above increase in tension would have no appreciable stiffening effect.

Appendix II.

S.T.A.E. Heights

Temperatures and Pressures.

Height Feet.	Pressure lbs/sq. in. abs.	Temperature °C.	Oxygen Delivery N.T.P. litres/min.
0	14.7	+15	0
5,000	12.22	+ 5.1	1.03
10,000	10.1	− 4.8	1.91
15,000	8.29	−14.7	2.66
20,000	6.75	−24.6	3.30
25,000	5.55	−34.5	4.78
30,000	4.36	−44.4	6
35,000	3.47	−54.3	7.03
40,000	2.72	−56.5	7.86

RACING SEAPLANES

BY

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Lecture read before the Yeovil Branch, February 27th, 1930.

The development of racing seaplanes has been so very rapid in the last few years that all other means of locomotion has been left a long way behind. Over 350 miles per hour has been reached in level flight by a machine controlled by a human being with a fair amount of ease and in comparative safety. A skilled human being it is true, but all advanced science requires skilled control. This development is the direct result of international competition and the pooling of national resources, without which it is safe to say we would still be flying at slower top speeds and without the valuable information which is the outcome of our racing experience. The knowledge gained in the design and construction of racing seaplanes puts aeronautical engineering far ahead of what may be termed its normal trend. Particularly is this so in the case of the engines. Racing conditions are much more exacting than Service requirements can ever be, high speeds and horse-power for cylinder capacity, supercharging, the reduction of fuel and oil consumptions and frontal area and low weight for horse-power, these are produced collectively in a few months whereas Service development under ordinary conditions would probably take much longer. The high speed machines built in 1929, their tests and final race in the Schneider Trophy last year, when they attracted probably the largest number of spectators ever seen at a competition in this country, have done much to keep aviation and its progress before the multitudes of this and all other countries; incidentally doing good to the British industry in general, for the foreign countries buying aircraft are bound to be influenced by the speeds attained and the newspaper publicity given to the racing success of British aircraft. The breaking of world's records and the winning of Schneider Trophies are only achieved by tremendous efforts on the parts of all concerned. The production of racing seaplanes has always been against time, and this handicap has added very considerably to the task confronting designers and constructors. The influence of racing on designs of all classes of machine, both military and civil, is bound to be marked and should tend to hasten their speedier development.

The problems to be faced in the quest of speed are fundamental to aircraft design and can be classified as:—

(*a*) Minimum resistance and weight in the machine.
(*b*) Maximum h.p. with minimum frontal area, weight and consumption in the engine.
(*c*) Maximum efficiency at top speed of airscrew.
(*d*) Satisfactory water performance for low resistance and weight in the floats.
(*e*) Successful functioning of the whole as a unit.

Some of these problems affect each other. The trend of thought in the general lay-out of the latest machines has narrowed itself down to the wire-braced low-wing monoplane as possessing the most efficient weight-drag

characteristics, coupled with a racing machine's important feature—the pilot's view. The S.4, a cantilevered high-wing monoplane, and the Gloster IV., a braced biplane, were both considered bad from the pilot's point of view.

The reduction of weight can be held responsible for the reduction of drag inasmuch as the size and therefore resistance of the wing, floats, bracing and length of fuselage are all affected by the weight of the machine.

The frontal area of the engine represents a large percentage of the fuselage frontal area, which is a measure of fuselage resistance.

Engine consumption of fuel and oil is expressed in weight, which is again resistance.

Good water performance is only gained at the expense of air resistance; therefore, anything better than that which is only just satisfactory means a further loss in aerodynamic resistance.

Extensive wind tunnel research is carried out on models in an effort to reduce resistance and component interference to a minimum and to check stability calculations. This research includes the following:—

(*a*) Tests on the complete model for pitching, rolling and yawing moments are very helpful in the determination of tail settings and control surfaces. With fin and tail planes built into the fuselage there is no adjustment possible, and therefore no margin of error allowable.

(*b*) Tests on fuselage models determine the best position of pilot's cockpit, position and shape of windscreen, headfairing, cylinder helmets, air intakes, etc.

(*c*) Tests on float models, both in the wind tunnel and in the tank, enable the best compromise to be made between air drag and water performance and determine their attitude on the machine.

(*d*) Comparative tests on lenticular and streamline bracing wires decided the adoption of the streamlines. These tests also indicated the accuracy necessary in manufacture to keep their drag to a minimum.

(*e*) Tests on scale model wings with various aerofoil sections give comparative aerodynamic characteristics.

(*f*) Tests on assembled components determine the induced drag due to interference.

The magnitude of this research work can be appreciated by those who are acquainted with wind tunnel work when it is realised that the tests enumerated are done for every design considered in the development of this type of machine.

Where any discrepancy with calculation occurs this is checked by further tests to obviate any doubt in the final results.

In addition to the wind tunnel and tank tests on models many full-scale tests are done. These include:—

(*a*) Tests on complete float for comparative resistance with snaphead and countersunk rivets in plating.

(*b*) Tests on cooling efficiency of every type of wing radiator considered on the racing machines.

(*c*) Tests on cooling efficiency of fuselage and fin oil tanks.

(*d*) Proof load tests on fuselages for strength of engine mounting and fuselage.

(*e*) Proof load tests on complete wing for strength and torsional rigidity against wing flutter.

The very extensive progress in racing engine development has had much to do with our racing seaplane successes. Our best speeds previous to 1929 were with a series of Napier engines, each being developed and hotted up in turn to give increased performance. In our latest speed efforts on the S.6, however, a departure from the Broad Arrow Napier to the Rolls-Royce " R " engine was

made with very happy results. Before doing this calculations were made and designs drawn out to determine the merits of each engine as a unit in the complete design. With the h.p. then promised the S.6, although about 18 per cent. heavier and possibly less manœuvrable, was a few miles per hour faster with the Rolls-Royce engine than with the Napier and so the Rolls engine was used. Subsequently it developed more h.p. than promised and fully justified its selection. The development of this Rolls-Royce standard " H " type Service engine to the most powerful aero engine in the world was remarkable, the transformation taking but nine months to accomplish.

The problems facing the racing engine designer can be said to be:—

(*a*) Minimum resistance of the engine with a shape that accommodates itself to fuselage streamlining.
(*b*) Exceptionally high power output.
(*c*) Minimum weight.
(*d*) Reliability at maximum power over long periods.
(*e*) Low fuel and oil consumption at maximum power.

To satisfy these requirements considerable research and test work was carried out. The numerous schemes of the designer to bring racing engines to their present stage of perfection would make a lecture of their own. The most important are:—

(*a*) Increased r.p.m.
(*b*) A number of stages of supercharging.
(*c*) Higher compression ratio.
(*d*) Strengthening of parts due to higher speeds, and higher temperature and pressure stresses.
(*e*) Special consideration on carburettor and fuel systems due to high velocities at intakes and quick machine manœuvres.

With racing engines turning over at over 3,000 r.p.m. gearing has been necessary to increase airscrew efficiency. The Rolls-Royce " R " engine was bench tested under conditions approaching as nearly as possible those produced in flight. To produce the airstream at the special venturi air intake another aero engine was employed to drive a fan giving a slipstream of over 300 miles per hour, and by this means approximately 20 per cent. increase in h.p. was obtained on the bench. With increased compression ratio tetra ethyl lead dope fuel is found necessary, and this coupled with high temperatures and pressures demand special precautions in the design of sparking plugs. Very close co-operation between machine and engine designer is essential to get the very best out of the final product. Engine problems become machine problems and *vice-versa*, and better compromises can be reached in this way than by each designer following his own train of thought regardless of the other. To illustrate this point I would mention some of the modifications made to the Rolls-Royce " R " engine to facilitate its accommodation in the S.6. The nose of the engine was lifted and lengthened, and the front engine feet centres were reduced to give a better fuselage entry. The supercharger and carburettor were moved back to enable the front wing spar to pass between the rear of the engine and the carburettor. This was found necessary to balance the machine. The blower intake was carried up and forward in the engine vee to fair into the water-header tank and windscreen. The water and oil connections on the engine were arranged to suit those on the water and oil radiators. The cam covers were specially designed to fair into the cylinder cowling and special provision made on the engine for cowling attachments.

The fuselage, in addition to housing the engine, forms a base for the attachment of float struts, wing, wing bracing and tail, and accommodates pilot, controls, instruments and water-heater and oil tanks. Careful planning of the

engine installation, pilot's cockpit and controls are necessary to keep the dimensions of the fuselage as small as possible and so cut down resistance (Fig. 1). The fairing into the fuselage of wings, float struts and wires has been thoroughly investigated on models in the wind tunnel in an endeavour to keep interference effects down to a minimum. The interference on the S.6, due to attachment of struts and wires to fuselage, wing and floats is considerable and accounts for some 16 per cent. of the total machine resistance. Care in the design is called for if these effects are to be kept small.

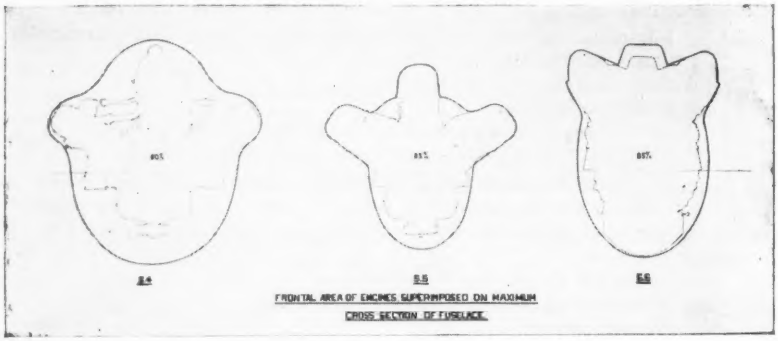

FIG. 1.

S.6 INTERFERENCE EFFECTS BETWEEN COMPONENTS.

Component.	% Component Drag.	% Interference.
Fuselage	17.8	—
Fin and rudder	2.3	− 0.6
Tail plane	3.4	− 1.9
Wing	27.7	− 1.0
Floats	21.4	+ 1.3
Struts	5.4	+ 4.6
Wires	5.6	+14.0
Totals	83.6%	16.4%

The shell and frames which form the engine mounting at the forward end are fitted very close around the engine and careful arrangement of pipes and connections for oil, water and fuel, engine controls, etc., is necessary to get them into the available space. Duralumin construction is used almost throughout in the fuselages of our latest machines. Apart from the engine bearers which are the only unbroken longitudinals, the engine and tail loads are taken through the duralumin plating, a number of thicknesses being required at the spar frame positions to reduce the stress to reasonable proportions. To check the calculations and test for stiffness proof load tests with two-thirds full factored loads are carried out on the completed fuselage. The load factors on the forward part of our latest racing fuselages are ten gravity, two torque and two thrust. With loads representing two-thirds these factors the measured twist on test was 0° 22′. No permanent set was found upon removal of the load and the fuselage was used in one of the completed machines. The stress wing loading on the fin and rudder is 6olbs. per sq. ft. and with two-thirds this load on test 0° 14′ twist was measured, again no permanent set being observed upon removal of load. The fuselage structure is therefore very stiff and amply strong enough to resist the

loads to which it is likely to be subjected. Flush riveting is used to keep skin friction to a minimum, full-scale tests on flush and snaphead riveting indicating a substantial saving in drag at high speeds in favour of the former method. In the S.6 the fin was built into the fuselage in stainless steel and formed the oil tank, which was virtually an oil cooler. The hot oil from the engine was conducted through coolers on the sides of the fuselage and sprayed on to the walls of the fin, the return being taken through another cooler on the under side of the fuselage back to the engine controls in fuselage. In the Gloster VI. a complete section of fuselage behind the pilot formed the oil tank, the controls to the tail being carried in tubes through the tank. Thin tubes round the fuselage formed the oil cooler and considerable experimenting was necessary to make them stand up to the oil pressures experienced. The tail plane of the S.6 was built throughout of duralumin and was built into the fuselage. The Gloster VI. tail was of wood construction and was adjustable for incidence on the ground. All tail controls were enclosed.

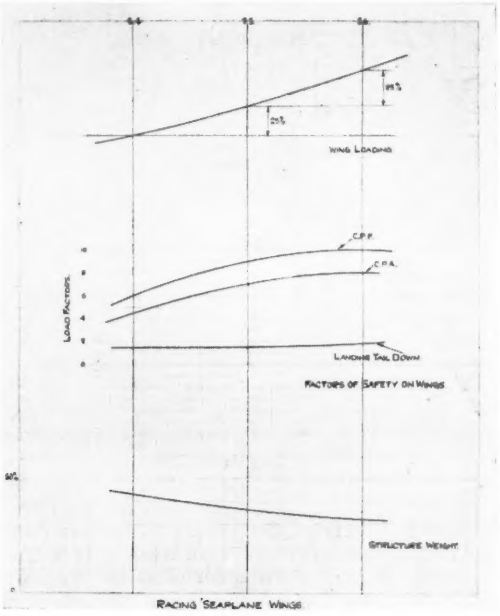

FIG. 2.

The interesting experiment of building the water-header tank of duralumin with the engine fireproof bulkhead and the skin of the fuselage forming side and top was made in the S.6 with success. Care was necessary in the design of the header tank to keep surging to a minimum, avoiding loss of water through the air vent and separating steam and water. A tank was tested on a Rolls-Royce " R " engine on the test bed with a view to eliminating these troubles before incorporation in the machine.

The improvement in wing design, both aerodynamical and structural, has had its bearing on the all-round improvement made in the speed machines. Although wing loading and load factors throughout the machine have increased considerably structure weights have substantially decreased (Fig. 2).

In order to do this, better and lighter methods of construction have been used. Duralumin has replaced wood in the wing construction, and copper and brass in the radiators. The development of light but strongly constructed smooth surface radiators, which transmit air loads to the wing spars, has materially helped in the reduction of weight and drag. Bracing wires of higher tensile steel and streamline sections have reduced both weight and drag. Streamline wires were used for the first time on our 1929 racers, although wind tunnel tests were carried out in some detail in connection with the S.5 in 1927. It was then found that the streamline wires increased the drag over lenticular wires by approximately 50 per cent. at 70ft. per second, this being attributed to inaccuracies in manu-

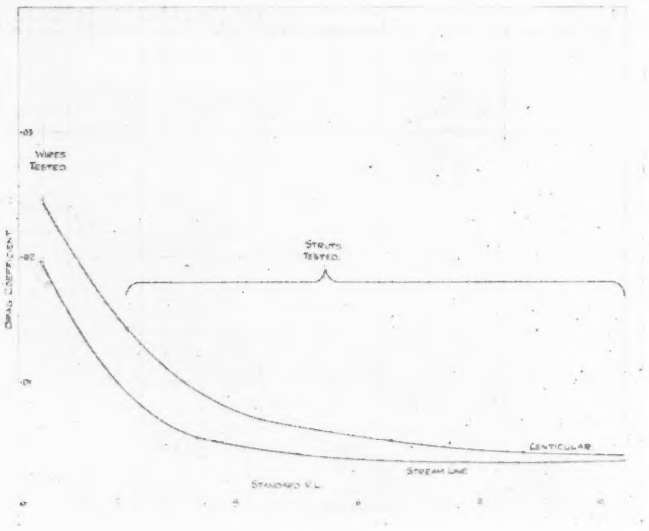

FIG. 3.

facture and a resultant bad aerodynamic shape. This was rectified, however, in our later machines and streamline wires were used in both the S.6 and Gloster VI., an estimated saving in drag of the order of 22 per cent. over the lenticulars resulting (Fig. 3). Even so the manufacturing difficulties encountered were numerous and hand finishing had to be resorted to to give the accuracy demanded to effect the saving in drag. Wind tunnel tests on inaccurate alignment are interesting inasmuch as they indicate an increase of drag of approximately 25 per cent. with an angle of yaw of 5° at 100ft. per second. As with our Service aircraft the lift bracing on the racers is duplicated, the duplication taking place through the incidence bracing from wing to floats. Cases have arisen in practice on the 1927 machines when bracing wires have broken in the air with no detriment to the machine—one would not expect the pilot to be amused though. To keep the landing wires correctly tensioned and prevent vibration—which also increases the drag—and yawing in flight, the Gloster VI. was fitted with special spring loading devices.

The selection of a wing section having good aerodynamic qualities with sufficient depth chord ratio for economic weight strength ratio wing construction and torsional stiffness against flutter is important in high speed aircraft design.

Cinematograph films of the S.5 indicated that the attitude at which the pilots landed the machine was not the best to give the maximum K_L of the aerofoil section used. Instead of the machine sitting down at 18° incidence, and getting the maximum K_L from the wings, only about 12° was reached. The experience gained on the S.5 had its effect in the choice of aerofoil in the S.6, an aerofoil giving K_L maximum at 14° and lower minimum drag being used in the later machine. Wind tunnel tests on the complete model determined the best setting of the wing on the machine for least drag at top speeds.

As a check on stress calculations full factored load tests are carried out on a complete wing for every racing seaplane built. In the case of the S.6 a wing complete with radiator was loaded at the R.A.E., Farnborough, and deflections measured at various points along the spars. An indication of the stiffness of this wing may be gained by realising that with full factor load of 10 a maximum of less than 2in. deflection was measured. This occurred at the wing tip. The radiator was kept full of water at 4lbs. per sq. inch pressure during the test. No fracture of any sort was found and the wing had no permanent set when the load was removed; in addition, no serious water leaks developed and the radiators were quite tight after removal of load. Tests of this sort on racing wings determine their torsional resistance to wing flutter, a danger in racing machine wing design which has to be carefully guarded against.

The load factor requirements on our racing machines, although they may seem high, only allow a reasonable margin of safety over the loading known to occur in flight during a sharp turn or when pulling out of dive. Tests measured by accelerometers in flight have recorded as many as seven times gravity loading on machine and pilot during a sharp turn. The American pilot, Doolittle, is reputed to have imposed *eleven* times gravity on his machine and himself when pulling out of a dive, but he is somewhat unusual in the way of human beings.

The control surfaces are of course small, rudder and elevator volumes of the order of .032 and .351 respectively being found satisfactory. Control is very sensitive and only small stick movement is necessary to give big change of attitude at high speeds. Even so our racers are extremely nice to fly once they are off the water, they handle just as nicely as our modern scouts and can be flown hands off. Extreme care is necessary in rigging the wings to counteract engine torque, and in this perhaps lies one of the most dangerous aspects of the machine's first test flight. Half a degree error of incidence at the point of attachment of the wires to the wing has been found in flight to require full aileron correction to maintain an even keel. With the wing all wire braced rigging is a laborious as well as an important process, half a turn on a wire, to give correct tension, tending to throw everything out of truth. The American precedent of fitting differential control is adopted on the later Gloster, but not on the Supermarine machines. It was found on the S.5 that aileron hinge pins which had worn slightly produced wing flutter of magnitude sufficient to cause the pilot much discomfort.

With the h.p. increasing and the machine becoming relatively smaller, as is the trend, water and oil cooling is becoming one of the biggest problems the racing machine designer has to face. Water cooling on racing machines has developed as surely as h.p. has increased in the engines. From the honeycomb type with its big resistance we have come to the surface type with no resistance and an appreciable saving in weight.

Fig. 4 illustrates curves showing the comparative efficiencies of radiators used for racing up to the present time. The advantages of covering the wing with a stress carrying smooth surface radiator of the type fitted on the S.6 are:—

(*a*) Saving in weight of wing structure or water cooling for practically no structure weight.

(*b*) No added resistance to the machine.

(*c*) Internal and external cooling giving increased heat dissipation.

This type was constructed of two thin duralumin sheets riveted together with $\frac{1}{16}$in. water-way between, troughs being fitted in the leading edge and the vicinity of the rear spar to form supply and returns to engine. These radiators in addition to the air passing over them externally were also cooled internally, special air inlet ducts being fitted on top and bottom surfaces of the wing at the tips and exhaust ducts near the fuselage. An increase of approximately 12 per cent. cooling was obtained with an internal air flow in the wing of about 35 miles per hour. When more h.p. than was anticipated was given by the engine extra radiators were fitted on the external plating of the floats. On one machine these took the form of long narrow strips about 12in. wide and in the other sheets of radiator were made to the shape of the nose and top forward of the front struts. Anxiety was felt with these float radiators with regard to their ability to stand the pressure of the big gravity head when the machine

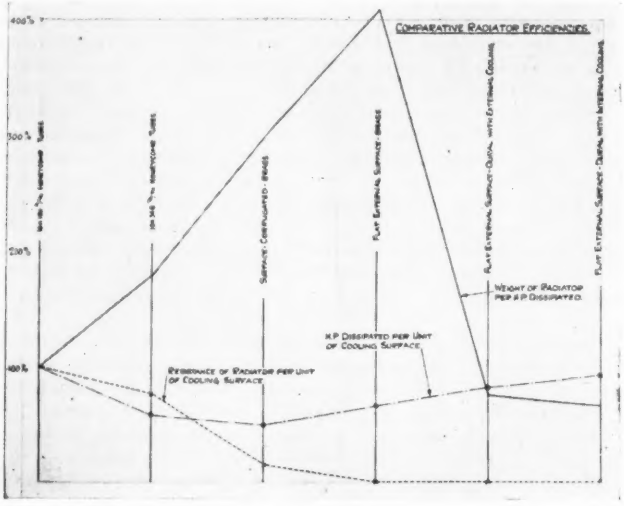
COMPARATIVE RADIATOR EFFICIENCIES.
400%
300%
200%
100%
SURFACE CORRUGATED TUBES
FLAT EXTERNAL SURFACE TUBES
FLAT EXTERNAL SURFACE CLOTH WITH EXTERNAL COOLING
FLAT EXTERNAL SURFACE CLOTH WITH INTERNAL COOLING
WEIGHT OF RADIATOR PER H.P. DISSIPATED.
H.P. DISSIPATED PER UNIT OF COOLING SURFACE.
RESISTANCE OF RADIATOR PER UNIT OF COOLING SURFACE.

FIG. 4.

was on a sharp turn and special valves were designed and made to relieve the pressure on the radiators. They were not fitted, however, when the radiators were found strong enough to stand up to the pressure anticipated without leaking.

Wind tunnel full-scale tests are carried out on racing surface radiators to determine their cooling efficiency and are valuable to the designer in determining the surface required with a given type of radiator to dissipate the h.p. which goes to heat in the engine. These tests also show how important the nose of the aerofoil is from a cooling point of view (Fig. 5).

There is undoubtedly much research work ahead on the subject of cooling and no doubt full advantage will be taken to use our existing machines in the further development of this subject.

The development of oil cooling has not perhaps been as rapid as that of water cooling. With practically all the wing being used for water radiators the designers have had no alternative but to turn their attention to the fuselage and tail to solve their oil cooling troubles. Our latest developments have led us to the fuselage tank and cooler in the Gloster VI., and the tail fin tank and side of fuselage coolers on the S.6. Research work was carried out full scale in the wind tunnel on both types of cooler and on various methods of oil spray-

ing on to the skin of the oil tank with satisfactory results. To help keep the engine crankcase and cylinders cool special inlet and exhaust louvres were fitted in the forward end of the fuselage and cylinder cowlings, these being arranged so that cold air was continually scavenging the engine compartment.

Very considerable progress has been made in float design as a result of our racing seaplane experience. From the sprung flat bottom types which helped win the early Schneider Trophies and which adorned all our Service seaplanes, we have come to the vee-bottomed unsprung type which is now standard practice on all up-to-date Service machines. This progress is the result of careful consideration in research on models and full-scale work and is the best compromise possible to take the machine off the water and land reasonably safely without sacrificing air resistance and weight (Fig. 6).

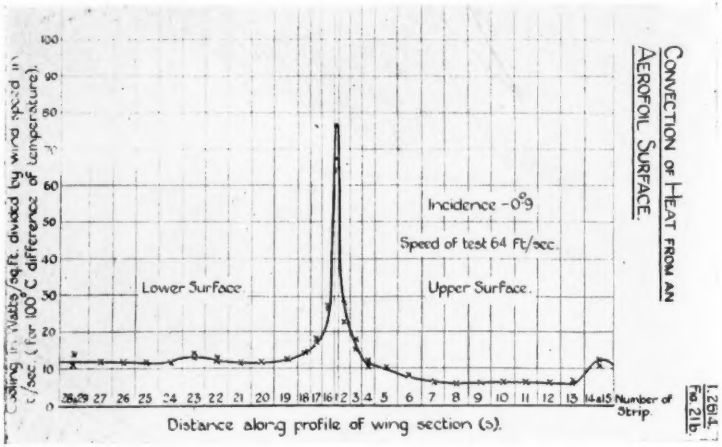
Convection of Heat from an Aerofoil Surface.
Incidence -0°9
Speed of test 64 Ft/sec.
Lower Surface
Upper Surface.
Cooling in Watts/sq.ft. divided by wind speed in C/sec. (For 100°C difference of temperature).
Distance along profile of wing section (s).
Number of Strip.
1.2614. Fig 21b.

FIG. 5.

It is difficult to assess the loss in water performance unless it is put down to

(*a*) The interference due to lowering the fuselage on the floats and consequent water drag on the fuselage and tail.

(*b*) The interference of the floats due to their narrow track and consequent water drag on each other.

(*c*) The reduction in reserve buoyancy and the fining out aft of the float lines giving large immersion and causing the floats to take up a big attitude and present a bluff entry.

The question of reserve buoyancy of racing seaplane floats is a very important one and has a large bearing on the machine's final seaworthiness; I say the machine's final seaworthiness because the completed article seems fated to come out at 10 per cent. to 15 per cent. overweight and make the floats look sorry for themselves when the machine is launched. The adopted shape of the floats is largely based on experience, and tank and wind tunnel tests. In the case of the S.6 float models were constructed to conform as near as possible to good airship forms and tested in the tank for water performance, which was bad, they dived under water at about 14 knots. The planing bottoms were modified, avoiding re-entrant curves, and an improvement resulted, but they were very dirty and unstable. Eventually the well-known flared planing bottom had to be introduced at the expense of air drag to make them clean enough to be seriously considered in the final design. Those of you who have seen racing seaplanes

performing on the water completely immersed in spray must think this reference to cleanliness an insult to float design. However, they do their job, if only just, and that is the object the designer sets them to do. In addition to the tank tests on float models a series of wind tunnel tests were carried out concurrently to determine the effect of the tank model modifications on air drag. They also

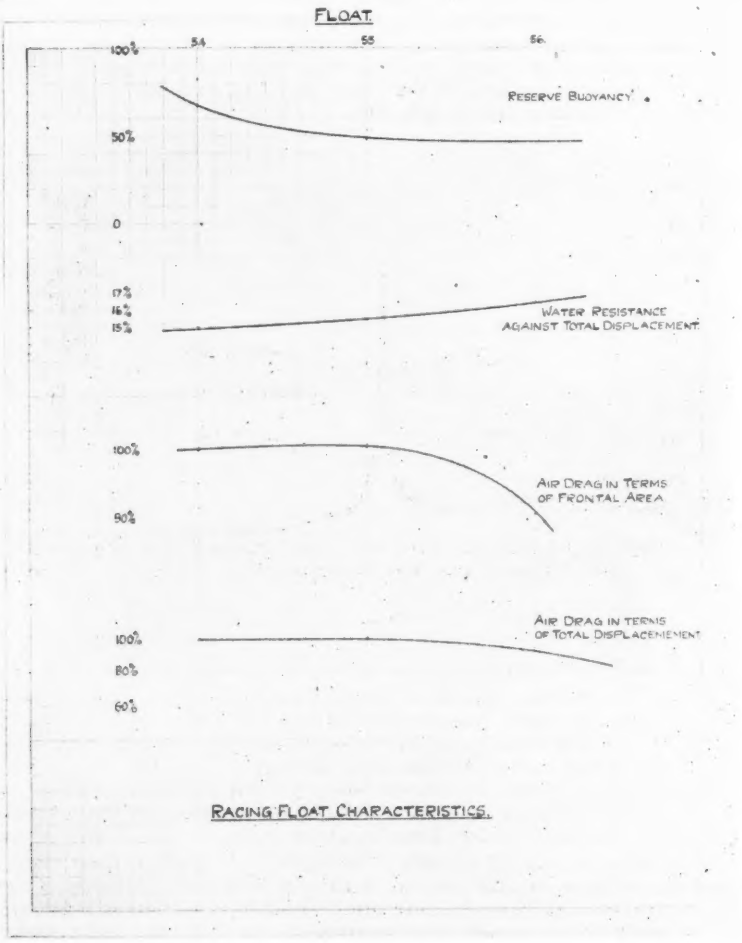

FIG. 6.

determined the best attitude of the floats on the machine for least air drag. This usually occurred at an attitude slightly nose down to the line of flight in the top speed case. Improvement has also been made in the reduction of weight for given strength in the latest design floats. How fine this was cut may be instanced by a case of slight deformation of plating and frame locally in an S.6 float during a heavy landing in tests on Southampton Water last year.

Duralumin is used throughout in the construction of the British newest types with the exception of the portions incorporating fuel tanks of stainless or tinned steel. The Italians still pin their faith to wood construction with probable loss in weight; against this, however, may be offset the beautiful smooth finish which they possess and which tends to reduce skin friction to a minimum. Actual comparative full-scale wind tunnel tests carried out on complete S.5 floats to determine air drag due to snap head and flush rivets in plating indicated an increase of ten miles per hour top speed in the machine in favour of the latter type of riveting. Full advantage of this was taken in last year's machines and all riveting was flush on the outside plating, both in floats and fuselages, with the exception of fuel and oil tanks and even then the rivet heads were reduced to the smallest possible margin.

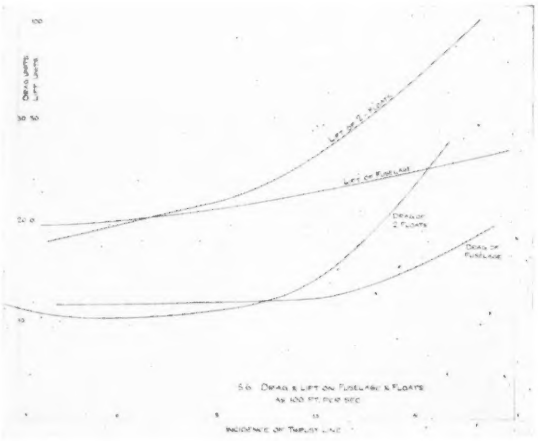

FIG. 7.

The severe requirements of high revolutions and tip speeds, the coping with high horse-powers and big speed ranges called for in racing seaplanes have been adequately met in the airscrew used, and in meeting these exacting requirements can be traced considerable progress in airscrew design. Duralumin has superseded wood in the construction and has had much to do in enabling high speeds in the engine to be efficiently used in thrust. It naturally follows that a fixed pitch airscrew designed for maximum efficiency at top speed has considerably reduced efficiency at lower speeds, and this combined with high frictional water resistance in the floats makes the take-off of high speed seaplanes a longer business than the designer cares for. After take-off the efficiency increases very rapidly and violent acceleration takes place—much to the discomfort of the pilot. Fig. 8 shows the airscrew efficiency of the S.6 throughout the speed range of the machine.

Gearing the engines has helped airscrew efficiency and enabled much higher engine revolutions to be used with consequent increase in engine output. The take-off of the S.5 with geared engine was much better than with the ungeared engine and the top speed was improved by ten m.p.h.

The airscrew used on the S.6 was a development of the Fairey Reed twisted blade type, previously used in the S.4 and S.5, the boss and blades in this case,

however, being forged in one piece from a duralumin billet. The Gloster VI airscrews were developed from their previous racing types and were duralumin solid forgings shaped by a special milling process and without twisting.

With fuel accounting for some 16 per cent. of our weight its disposition in the machine is one of some difficulty. The floats seem the obvious place to put it since they have to support its weight whether it is housed in them or not, but the designer has to do so because there is nowhere else available. The twin-float tanks, fitted in our latest machines, complicate the fuel systems somewhat, but have compensation in another way; as they are arranged they help balance the engine torque loads, which have the tendency to push the nose of one float under when taxying on the water. This was so pronounced on the S.6 that a larger fuel tank was built into the port float and the float enlarged to cope with the engine torque and full load of fuel. Two fuel pumps were necessary on the engine to cope with the supply of fuel required to keep the engine at full power. The Rolls-Royce " R " engine consumption at full power was of the order of two gallons per minute—in other words, fuel consumed in the

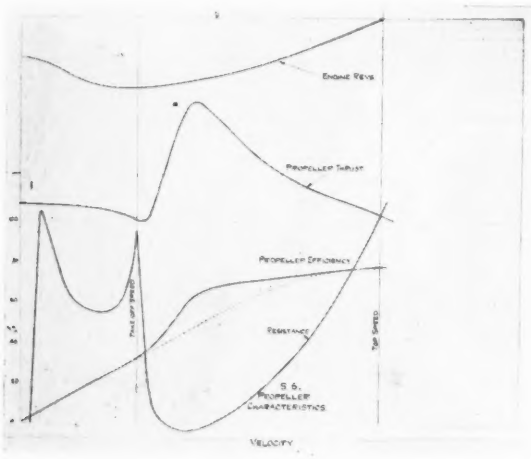

FIG. 8.

same time that it takes the average mechanic to pour a two-gallon can of petrol into a petrol tank! Care had to be taken in the design of the fuel system to ensure that the engine had sufficient fuel supplied to keep it at full power when the machine was doing a turn, during which time the suction lift on the pump was broken owing to the increased gravity head on the system. This was overcome by the introduction of a small pressure tank in the fuselage and an arrangement of special valves which supplied fuel to the engine with the pump suction lift broken, and evenly distributed the overflow to the float tanks in level flight and at high fuel pump speeds.

Improvement in windscreening and cockpit ventilation has been brought about in our latest racing machines. Of necessity the pilot's head is included in the general fuselage streamlining which permits of no excrescences and thus with the windscreen fairing into the centre engine cylinder block or air intake the view immediately forward is *nil*. By a careful arrangement of side and top glass panels, however, a reasonable angle forward and upward is obtained.

To overcome the " misting " of the glass and " hammering " on top of the pilot's head, specially arranged deflectors on the sides and top of the wind-screens are fitted. These deflectors enable the pilot to see straight ahead without being exposed to the high air stream and are invaluable when landing in a water-way which is not free of traffic. We have not yet got the all-enclosed cockpit in our racing machine, although by so doing air resistance on the fuselage would be reduced, because whatever other indignities we may subject the pilot to he must be able to see under all conditions and there is no safeguard to spray or mist on the glass. Hinged lids were made in an effort to give a smooth air flow over the cockpit in our 1929 racers, but have not yet been tried out in flight. Unbearably hot conditions prevail in the cockpit unless care is taken with regard to ventilation. Air scoops in the wind screen are arranged so that air free from exhaust gases plays on to the pilot's face without excessive draught. Exhaust louvres are arranged to clear the cockpit of heat and fuel and oil fumes. A number of flight tests are necessary before these difficulties are overcome and the personal tastes of the pilots satisfied.

The first flight tests on racing aircraft are perhaps the worst feature of the whole subject, from the designer's and everyone else's point of view. While every precaution is taken throughout the design and production stages the unknown is very prevalent until the pilot has had his first " go." It is so easy for these high speed machines to have a peculiarity, maybe on the water, maybe in the air. We have simply to examine our Italian and French competitors' records to realise the truth of this. On the water up to the time the floats are hydroplaning the pilot can be said to have no longitudinal control, the floats just behave as they will. Tank tests on models only give their behaviour up to 37 knots and beyond this anything up to their 80 to 100 m.p.h. take-off speed must be conjecture. Inefficient airscrews, small reserve buoyancy, high water resistance, and high wing loading are all against taxying and take-off, and make the test pilot's task an unenviable one. Once having got the feel of the machine by frequent testing, however, no great difficulty is experienced in taking-off. In the air the fruit of the extensive wind tunnel work on stability is reaped, the control being very good even if somewhat sensitive. At high speeds the sudden change of attitudes which is possible calls for great physical fitness in the pilot, and special training in this class of work is necessary to accustom the human organs to stand the excessive strain put upon them. I think it is a fact that all the R.A.F. high speed pilots of 1929 have admitted to " blanking out," that is, becoming temporarily unconscious during sharp turns in the racing machines. Landing speeds of 80 to 100 m.p.h. call for much skill in piloting. Owing to the extremely flat gliding angle, long unobstructed water-ways are required for landing, the deceleration after closing the throttle being very slow and gradual down to the stalling speed.

The skill, patience and enthusiasm shown by the pilots during the testing and racing of the machines has contributed very largely to the progress which racing seaplanes have made. Much work is still ahead in the further development of these machines and many avenues are open to improvement. It is to be hoped that, having got so far, we will not sit back and be content to let our foreign competitors make up their leeway and call the tune.

With regard to the future, there is little doubt that higher speeds can and will be obtained as a result of the experience so far gained and the research still necessary to combine with that experience. Our engine designers can give us still more power with still smaller size, weight, consumption, etc. We can build machines with less resistance and weight, and dissipate all the h.p. in heat they care to lose. Someone will come along with a variable gear ratio or a variable pitch airscrew, and we will start all over again to put up better top speeds.

Discussion

Mr. Davenport: He thought it was a remarkable achievement for racing seaplanes, such as the S.6, to have been produced with such a low structure weight, but he assumed that in arriving at this figure the surface covering of the wings was considered not as structure weight but as part of the cooling system. It was very interesting to note the interference effects between the various components, and the most remarkable appeared to be the very high increase of drag caused by the addition of the wires to the floats, wings and fuselage, and the reduced drag due to the addition of fin and rudder to the fuselage, and he would like to ask if the lecturer had any theory of general application which would account for these effects.

Mr. Holroyd: It was quite true that the structure weight mentioned did not include the weight of the wing radiators. With reference to the interference effect, he could only state that careful tests were carried out with components separately, but when the components were brought together the negative or positive interferences quoted were actually measured. With reference to the wires, he mentioned that the streamline portion was in all except one position continuous right up to the wing surface. As regards the general application of the lessons learnt from these interference effects, he could state that it had been found better to keep the full outline of the strut section until it actually met the body of float, and not to increase the size and flare with a large radius nor to decrease the size at the ends.

Captain Hill: He would like further information regarding the second hump of the drag curve, as it seemed to be rather a remarkable increase of drag just at take-off speed. It was also interesting to see from these curves that the propeller was in a stalled condition at take-off speed, and had in fact very little reserve of thrust over the combined air and water drag.

Mr. Holroyd: In reply to the last portion of the question, this was so; and with reference to the hump in the curve, this was due to the attitude taken up by the machine just before taking off, the floats trimming at such an angle that the resistance at the increased speed built up very rapidly. In this connection, he mentioned that the present facilities for tank tests did not allow for measurements being taken at a higher speed than about 50 knots, and between this speed and the speed of take-off, which was approximately 100 miles per hour, the attitude of the floats was a matter of conjecture, thus making the initial tests of this class of machine a very dangerous and trying experience.

Mr. Gaunt: Is the oil sprayed inside the fin cooling tank by means of a rotor? Are the oil and water pipes of steel?

Mr. Holroyd: Centrifugal rotor sprayers had been tried, but it was found that a series of holes in the tube served the purpose quite as well. The pipes used in the systems were of copper.

Mr. Davenport: Why is stainless steel used for the fin which formed the oil tank instead of duralumin?

Mr. Holroyd: It was partly because of structural reasons and partly because it was considered unwise to experiment with duralumin in this position, as there was so little time available, and they felt safer in using stainless steel, although they found that in the soldering process a certain amount of buckling took place.

A Member: What is the fuel consumption of the engine?

Mr. Holroyd: About 120 gallons per hour.

Mr. Johnston: Are the chassis struts of streamline tubing or round tubing faired?

Mr. Holroyd: Round tubing faired to enclose the pipe lines.

Mr. Gaunt: Was the S.6 fitted with rudder bar or were pedals used to save space?

Mr. HOLROYD: Sliding pedals were used for rudder controls.

Mr. GAUNT: Was the control stick split in order to more easily allow for the required movement in the small fuselage?

Mr. HOLROYD: The joy stick was not of the split type as very little movement was necessary in the cockpit, the increase being obtained on the counter-shaft.

Captain HILL: Were the controls of the push and pull type or of cable?

Mr. HOLROYD: Cable.

Mr. DAVENPORT: Why had it not been arranged for the engine makers to make their engine crankcase follow the lines of the fuselage, and so actually form the bottom fairing instead of having the fuselage shell in close proximity, as by doing so they would have helped the oil cooling considerably?

Mr. HOLROYD: This scheme had been thought of, and put up to the engine makers, but there were several difficulties which prevented its adoption.

Captain KEEP: Is there not difficulty in the use of streamline wires, because their adjustment entailed a complete turn, whereas with the lenticular wire half turns could be used?

Mr. HOLROYD: This was overcome by using fine threads on the ends of wires and in the fork-ends.

Mr. RATCLIFFE: Have differential aileron controls been tried on the plane itself?

Mr. HOLROYD: These had been designed, but actually found to be unnecessary, the normal control being quite adequate, for the machine handled in the air just like a normal scout, and it was possible to fly hands off for two or three minutes and carry out all manœuvres with the greatest of ease.

A MEMBER: Is the duralumin used on these racing machines anodically treated?

Mr. HOLROYD: Yes.

A MEMBER: What thickness of duralumin is adopted for the wing radiators?

Mr. HOLROYD: 24 gauge.

A MEMBER: He had heard that the oil pressure gauge on the 1927 racers had been removed just before the race to make sure there was no danger of a failure in the gauge or pipe line and so involving possible loss of oil. He would like to ask whether the same procedure was adopted for the 1929 racers, or whether a special type of oil gauge was used with a diaphragm interposed to obviate danger from possible breakage?

Mr. HOLROYD: So far as he was aware the oil gauge and the other standard instruments were carried during the race itself, and the oil gauge he thought was of a standard type.

A MEMBER: Were the steel bracing wires corroded at all by the salt water?

Mr. HOLROYD: No corrosion had taken place in the short time during which these wires were used. In any case, the machines are thoroughly overhauled after ten flying hours and any corroded parts would then be replaced.

A formal vote of thanks was proposed by Captain Keep and seconded by Mr. J. W. Ratcliffe, and the meeting closed.

REVIEWS

Transport Aviation

Archibald Black. New York. $5.00.

This is the second edition, revised and completely re-written, of Mr. Black's book. The book is very uneven, much of that due to the fact that transport companies jealously guard the secrets of their operating costs. Chapter XVII, on the basis of cost estimates, opens with the sentence, " Prediction of the cost of operating airplanes is not an exact science." The author gives a list of sixteen factors affecting operating cost and investment, a sound list, and proceeds to analyse the effect of each of these factors. He points out, and rightly in the opinion of the reviewer, that the cost of operation must increase rapidly with the increase in distance over which a flight is made without stops. He is conservative as regards speed, suggesting 90-100 m.p.h., but higher speeds are essential and undoubtedly a cruising speed of 150 m.p.h. with a low landing speed will be characteristic of the aeroplane of the comparatively near future. In the chapter on the influence of design upon operating cost are some interesting figures showing how costs go up rapidly on journeys of over 400-500 miles at present cruising speeds. With many of the conclusions there may be disagreement by designers and operating companies, but Mr. Black has done a valuable service in gathering together what material is available and placing it in a proper sequence. His conclusions, on the whole, can only be combated by air transport companies themselves, and to do that would mean giving away their own figures. And air transport companies, at present, are too short-sighted to see that the policy of success is to tell the truth, the whole truth and nothing but the truth.

Air Power and the Cities

J. M. Spaight. Longmans, Green and Co. 15/- net.

Mr. J. M. Spaight in his new book, " Air Power and the Cities," deals with the menace to bombardment from the air during war of cities which are not, in the usual accepted sense of the term, military objectives.

" Air power is essentially a moral-breaking force, and as such it has enormous and unique possibilities. The twofold end sought—moral overthrow and military overthrow—can be obtained if the paralysing of munitionment is recognised, as it should be, as being the grand mission of the air arm. In proportion as it is so recognised, the air menace to the cities will be circumscribed and diminished. Disarmament assumes in the philosophy of air power thus outlined a place of prime importance. Air power is envisaged as a disarming, a preventive, a war-breaking rather than a war-rating force. The subject of this book is thus related not only to the present era of ' private ' wars, but to the era, sure to come, of organised and enforced world peace."

The above extract from the preface outlines the scope of the book. Mr. Spaight considers the bombardment of unfortified and undefended towns in the past by warships as an essential study for the problems which arise in connection with the operations of raiding and bombing aircraft. He begins with the remarkable bombardment of Greytown, Nicaragua, by the American warship *Cyane*, on July 13th, 1854, and continues the story through the bombardment of Odessa in the same year, Taranroy in 1855, Canton 1856, Kagosima 1863, Valparaiso 1866, to the bombardment of the Great War, Scarborough in 1914, Dedeagatch in 1915, and Lowestoft and Yarmouth 1916.

Mr. Spaight develops the theme that air power will not be used for the destruction of cities, for the wholesale slaughter of so-called " non-combatants." As he rightly points out, the Great War proved the mastery of the machine in all its force. He suggests that the function of the air arm is to concentrate on " killing " machines rather than that of men.

" Smash the machines and the machines which make the machines. Smash the turbines, the dynamos, the mighty steam presses, the mammoth steel hammers, which forge and fashion the instruments of destruction. Smash the whole metallic substructure of armed strength. Make the war of machinery impossible. Air power can do that and air power can do it alone. It can strangle munitionment as sea power strangles maritime trade. That is why the air arm is the greatest of the arms of war."

Air power is the greatest power for universal peace the world has ever known, not only for its actual power in time of war, but for its international bonding of nations in time of peace. Mr. Spaight has hammered the point home with sound argument, and his book is one which should be read by all those who cry aloud for the lessening of air forces. A mighty air force is a mighty instrument of peace, in that in it lies the one possibility of cutting the head off the god of war and destroying the machine-made brain whose only thought is the destruction of human life and hope.

Definitions and Formulæ for Students (Aeronautics)

John D. Frier. Pitmans. 6d.

Here is an excellent idea, but unhappily it has been spoilt by trying to put a quart into a pint pot. This little booklet of thirty small pages (5 in. by 4 in.) contains fifteen pages of definitions based on the Royal Aeronautical Society's Glossary of Aeronautical Terms. In view of the statement made in the preface that " some previous knowledge on the part of the reader is assumed," it is difficult to see why these definitions are given. Without already, indeed, being thoroughly conversant with these definitions, no student would understand the section half of the book giving formulæ, and, alternatively, he could not understand the second half of the book by digesting the first half. Far better use of the space could have been made by devoting it to formulæ of use to the student. Although the book may have a certain very limited use, it is clear that it can only be limited when it is stated that the whole field of aeronautical formulæ is crowded in fifteen small pages. The compiler admits, " Owing to the limited space available, a number of formulæ have been omitted because of their technical character, *e.g.*, the generalised theories of three moments." Approximate formulæ are given, and really, in aeronautics, approximate formulæ will not do. Aeronautical engineering must necessarily, by its very limitation of weight/strength ratio, be as exact as human endeavour can make it.

All the World's Aircraft of 1929

Compiled and edited by C. G. Grey, Leonard Bridgman and L. Howard Flanders. Sampson Low. 42/-.

This annual reference book, covering both civil and military aviation, has now reached its nineteenth year of issue and has become as much a standard work as " Who's Who " and Whitaker's in other spheres. It is a remarkable tribute to the rapidly rising tide of air progress, and to read the annual through is an education to the most enthusiastic aviator. Here, digested and properly arranged, are particulars of aircraft, airships and aero engines, which could not otherwise be obtained without an immense amount of labour. Nearly every aeroplane described is new, few of those which appeared in the 1928 issue being described in this issue, and then only in order to add new information. Some

idea of progress, therefore, may be obtained from the statement that 664 aircraft are described. These aeroplanes only include tested aircraft, and the editors have excluded, and rightly so, all those which have been produced experimentally and have not fulfilled the expectations of their designers. Similar progress is shown by the increased space devoted to the engine and airship sections.

A remarkable article is printed in the historical section under Russia. It is a translation of an article by V. A. Zarzar, General Manager of the Civil Aviation of the Union of Russia Soviets, dealing with the five-year plan. Under this plan the progress of Russian civil aviation is rapid. If the claims made by Zarzar bear any relation to the truth Russia is developing its internal air lines with one eye—their need in war. Part of the organisation includes the Osoaviakkim Company formed by the union, among others of the Voluntary Chemistry, Chemistry and Aviation and Defence Increase Companies. This resolves into a chemical warfare from the air. The Russian Government have never made any secret of aiming at having the most powerful air arm in the world. At present the Red Air Fleet consists of about 90 squadrons of 12 machines each.